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ANALYSIS OF GPS TIMING DATA IN SUPPORT OF OMEGA SYSTEM SYNCHRONIZATION: A CESIUM STABILITY STUDY

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16. ABSTRACT

The use of GPS precise time-transfer has the potential for improving the accuracy and the efficiency of Omega synchronization. Under the present scheme of synchronization, designed long before the availability of global time-transfer, synchronization adjustments were made once per week. These adjustments are based on a statistical estimate of timing errors derived from very-long-baseline reciprocal path phase measurements. This report examines an alternate approach to synchronization using GPS as the primary means of measuring timing errors at individual stations, independent of other stations. A Covariance Simulation Program (CSP) has been developed to simulate the behavior of cesium frequency standards under various error correction schemes. The CSP is based on a cesium stability model and accepts actual Omega station data as input to model the rate of growth of timing errors under various scenarios. The results of the CSP can then be used to support decisions on the architecture of the synchronization process. Associated with this report is an Addendum showing sample CSP results and a CSP User's Guide.

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1. EXECUTIVE SUMMARY

This report provides a description of the Covariance Simulation Program (CSP) developed as a tool to examine cesium clock stability and to investigate the utilization of Global Positioning System (GPS) data in the Omega system cesium clock synchronization process. The current process of maintaining Omega system network synchronization, that is synchronization of each Omega Station (OMSTA) to "Omega System Time", requires several steps. The long term synchronization of each OMSTA to a common time standard has historically been accomplished using reciprocal path Omega readings. Such readings are processed at a central location to provide phase corrections required for each transmitter signal. Because of telecommunication limitations, these long term phase corrections are ordered by the central location at weekly intervals. Short term synchronization of the network is achieved using the available cesium beam frequency standards, or clocks, located at each OMSTA. A correspondence between Omega System Time and Universal Coordinated Time (UTC) can also be achieved since 4 of the 5 northern hemisphere Omega Stations can obtain Loran-C measurements, which provide a link to UTC. Using this data, the central location can regulate the entire system so that Omega system time provides a close approximation to UTC.

The process of re-establishing "coarse" synchronization, should synchronization be lost due to a long term power outage for example, is difficult given the nature of Omega. To facilitate the restoration of "coarse" synchronization, GPS receivers were installed at all Omega stations in the mid-1980's. GPS is currently an experimental system and cannot be relied on as an exclusive source of synchronization for the Omega network. Motivated in part by the greater accuracy of GPS relative to Loran-C, and GPS world-wide availability, GPS timing data from one station was incorporated into the synchronization process in 1985. The results from this initial experience led to an expanded program involving GPS data from three other stations in 1988. The cumulative results of these efforts indicate that GPS could play a more prominent role in the Omega synchronization process once GPS becomes fully operational. The precise manner in which GPS data is used must be carefully assessed.

The CSP was developed to aid in this assessment process. The main element of the CSP is a six state Kalman filter designed to process GPS/cesium and cesium/cesium phase offset measurements, and to thus provide cesium phase offset estimates. The measurements that drive the filter consist of field recorded data obtained from the Omega Stations in Norway and Hawaii.

These two stations provide special data recording capabilities that allow the raw measurements to be recorded. To fulfill the role of an analysis tool, the CSP allows the user great flexibility in defining system parameters, most notably the measurement update interval. Using the CSP, several hypothesized measurement/ corrections incorporation schedules were examined. Results from the initial CSP runs, presented in the form of plots both within this report and in the accompanying addendum, confirm the integrity of the basic filter design. The phase offset residual plots are key to evaluating the impact of varying measurement incorporation intervals on the reliability of the CSP filter computed phase offset estimates. These phase offset residuals are basically the difference between the CSP computed phase offset estimates and the measured phase offsets. Thus they provide a means of measuring the "error" in the CSP estimates, relative to the GPS data, between the scheduled measurement incorporations. These "errors" were observed to grow only slightly as the interval between measurement updates was lengthened. In all instances these maximum errors remained below the 300 nanosecond level.

2. INTRODUCTION

2.1 BACKGROUND

The Omega Navigation System provides a world-wide navigation capability through the use of eight widely dispersed transmitters operating in the Very Low Frequency (VLF) band. The system user employs phase-of-arrival measurements to obtain position information. The proper operation of the Omega system therefore requires careful synchronization of all eight stations to a common time standard. Each transmitting station contains an ensemble of three cesium beam frequency standards which are used to control the short term synchronization of the network. Longer term synchronization has historically been achieved by the processing of daily reciprocal path Omega readings at a central location. Because of the telecommunications delays involved, phase corrections associated with this longer term control are ordered by the central location weekly. The effect of this control scheme is to maintain what is termed "internal synchronization." This concept describes the relationship of the timing of any individual station to Omega system time. Since 4 of the 5 northern hemisphere Omega stations can obtain Loran-C system measurements, and since Loran-C measurements provide a link to Univeral Coordinated Time (UTC), the central location can also steer the entire system so that, ideally, Omega system time equals UTC (ignoring the effects of leap seconds). This process maintains the "fine" synchronization of the system.

The nature of Omega is such that it is difficult to establish "coarse" synchronization if, for example, a long power interruption causes it to be lost. GPS receivers were placed at all the Omega stations in the mid-1980's to greatly facilitate the restoration of coarse synchronization, should it ever be lost.

Beginning in 1985, GPS timing data was used as an input to the synchronization process at one OMSTA, as an auxiliary input emulating Loran-C. After proving effective in this role for over 2 years, GPS data was incorporated into the process at three other OMSTAs. The results indicate that once GPS becomes an operational system, it could play a greater role in Omega synchronization. However, the exact nature of the role must be carefully studied. The initial step in this study is described herein.

2.2 SCOPE AND PURPOSE

In essence the study described in this report examines the performance to be expected if the Omega network synchronization were derived exclusively from the cesium and GPS readings available at a given station. A program called the Covariance Simulation Program (CSP) was developed to characterize the performance. Chapter 3 of the report provides a brief description of the Omega station equipment, concentrating on the source of the data used in this study and its relationship to other equipment. Chapter 4 describes the development of the CSP, the main element of which is a 6 state Kalman filter designed to estimate cesium phase offsets based on cesium/GPS and cesium/cesium measurements. It also provides details of the filter algorithm and a description of how CSP can be used to produce simulated results under new synchronization methods. An overview of the CSP-user interface is also provided. Additional details of the CSP system operation are contained in a User's Guide (Reference 1). Chapter 5 presents and discusses the results from initial testing of the CSP using OMSTA Norway and Hawaii data. The purposes of these tests were to confirm the integrity of the basic filter design and to study the behavior of the cesium clocks located at these stations. A complete set of data plots is provided in an addendum to this report (Reference 2).

3. DISCUSSION OF GPS/OMEGA TIMING DATA

3.1 REVIEW OF RELEVANT OMEGA STATION EQUIPMENT

This section provides a brief description of those pieces of the Omega system relevant to this study. Presently, all transmitting stations are equipped with DATUM Model 9390-5007 GPS Time/Frequency monitors. In their current capacity, the GPS measurements are used as part of a process for synchronization of the Omega system epoch to UTC. The eight transmitting stations observe, record, and report phase difference measurements of UTC minus online Omega Signal Format Generator (OMSFOG). The individual station's internal delay constant is then applied to obtain UTC minus station epoch.

3.2 INDIVIDUAL TRANSMITTING STATION INPUTS

Omega time at each station is derived from three Hewlett-Packard CAQI-5061A Cesium Beam Frequency Standards, which are part of Unit 2 of the AN/FRN-30 Timing-Control Set. Each frequency standard drives an OMSFOG. The block diagram in Figure 3.2-1 depicts the configuration of equipment for measurement of Omega epoch with the GPS implementation. The three frequency standards and their associated OMSFOGs are designated A, B, and C, as shown in Table 3.2-1 for OMSTAs Norway and Hawaii. One frequency standard (and its associated

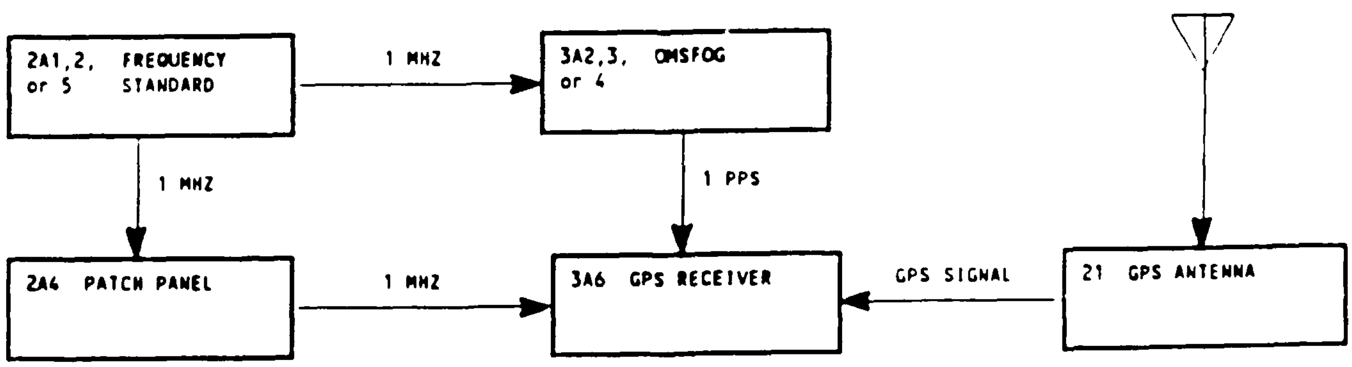

Figure 3.2-1 Configuration of Equipment for Measurement of Omega Epoch by GPS

TABLE 3.2-1

FREQUENCY STANDARD - OMSFOG CONFIGURATION

STATION	FREQUENCY STANDARD				OMSFOG	
	FUNCTION	CESIUM	DESIGNATOR	UNIT	UNIT	DESIGNATOR
Norway	Online	486	A	2A1	3A2	A
	Secondary	017	B	2A2	3A3	B
	Primary	124	C	2A5	3A4	C
Hawaii	Online	529	A	2A1	3A2	A
	Primary	554	B	2A2	3A3	B
	Secondary	349	C	2A5	3A4	C

OMSFOG) is designated the online unit. The two remaining frequency standards are designated primary and secondary and are held in reserve in case of failure of the online unit. Table 3.2-1 shows the primary and secondary cesium designations at OMSTA Norway are reversed from those at OMSTA Hawaii. This system setup will affect the order of measurements incorporated into the CSP as discussed in Section 4.3 of the report.

It is important to reiterate that the current synchronization process uses reciprocal path Omega, Loran-C and GPS readings for long term synchronization. In this study we will concentrate only on GPS and cesium readings taken at each station. The study is facilitated by the fact that special equipment, known as the United States Naval Observatory Remote Data Acquisition System (USNO RDAS), has been installed at the OMSTAs Norway and Hawaii. The USNO RDAS block diagrams are shown in Figures 3.2-2 and 3.2-3. At these stations, the relative phase of all three frequency standards is continuously monitored and recorded by an HP9915B computer. An HP59307 Very High Frequency (VHF) switch is used to compare 1 pulse per second (PPS) signals from all three cesiums on channels A2, B1 and B2 to the 1 PPS signal from the DATUM GPS receiver on channel A1. Every morning a USNO operator connects to a Hewlett-Packard computer through a 3451 modem and collects the Precise Time/Time Interval (PTTI) data saved thus far in the current week. Once a week the data banks of Hewlett-Packard computers at OMSTAs Norway and Hawaii are cleared and the data recording cycle starts anew. At USNO, a Hewlett-Packard

1000 computer is used to save the PTTI data for collection periods exceeding one week. Selected portions of this data, discussed in the next section, were utilized in the CSP.

3.3 DATA FORMAT

The USNO RDAS was used to obtain the input data for the CSP. Figure 3.3-1 is an actual sample of the PTTI data collected by USNO. Each data record field depicted in Figure 3.3-1 for OMSTA Norway is described in Table 3.3-1. Table 3.3-2 contains similar record field descriptions for PTTI data provided by OMSTA Hawaii. Of 20 available data fields the following six (appearing with asterisks in Tables 3.3-1, 3.3-2, and Figure 3.3-1) data types are utilized by the CSP directly:

1. Modified Julian Day (MJD)

2. GMT Time of the Day (TOD)

3. Time difference between GPS time and secondary cesium clock (GPS-CS017) for OMSTA Norway.

   Time difference between GPS time and primary cesium clock (GPS-CS554) for OMSTA Hawaii.

4. Time difference between GPS time and primary cesium clock (GPS-CS124) for OMSTA Norway.

   Time difference between GPS time and secondary cesium clock (GPS-CS349) for OMSTA Hawaii.

5. Time difference between online and secondary cesium clocks (CS486-CS017) for OMSTA Norway.

   Time difference between online and primary cesium clocks (CS529-CS554) for OMSTA Hawaii.

6. Time difference between online and primary cesium clocks (CS486-CS124) for OMSTA Norway.

   Time difference between online and secondary cesium clocks (CS529-CS349) for OMSTA Hawaii.

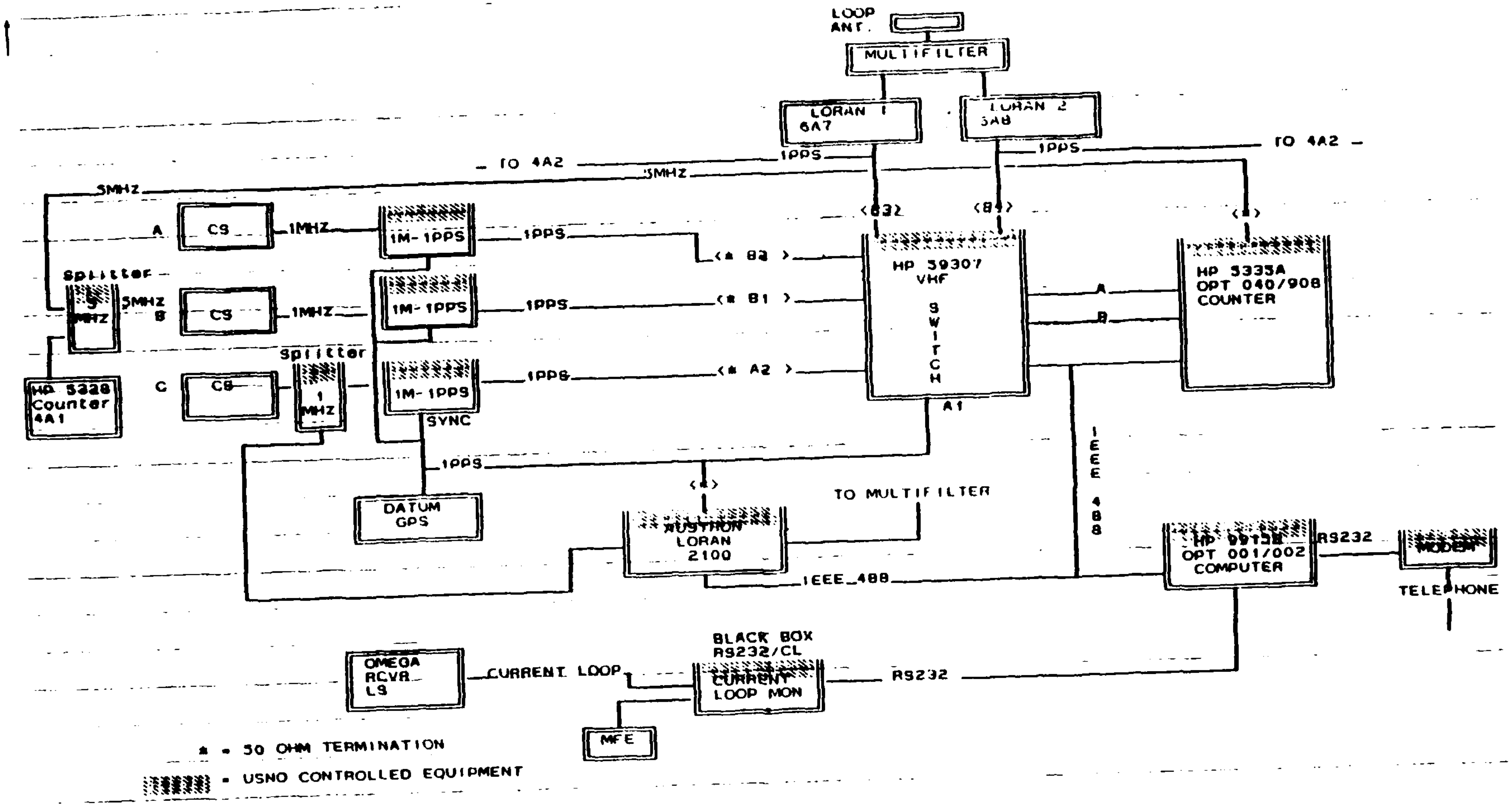

Figure 3.2-2 USNO Remote Data Acquisition System (OMSTA Norway)

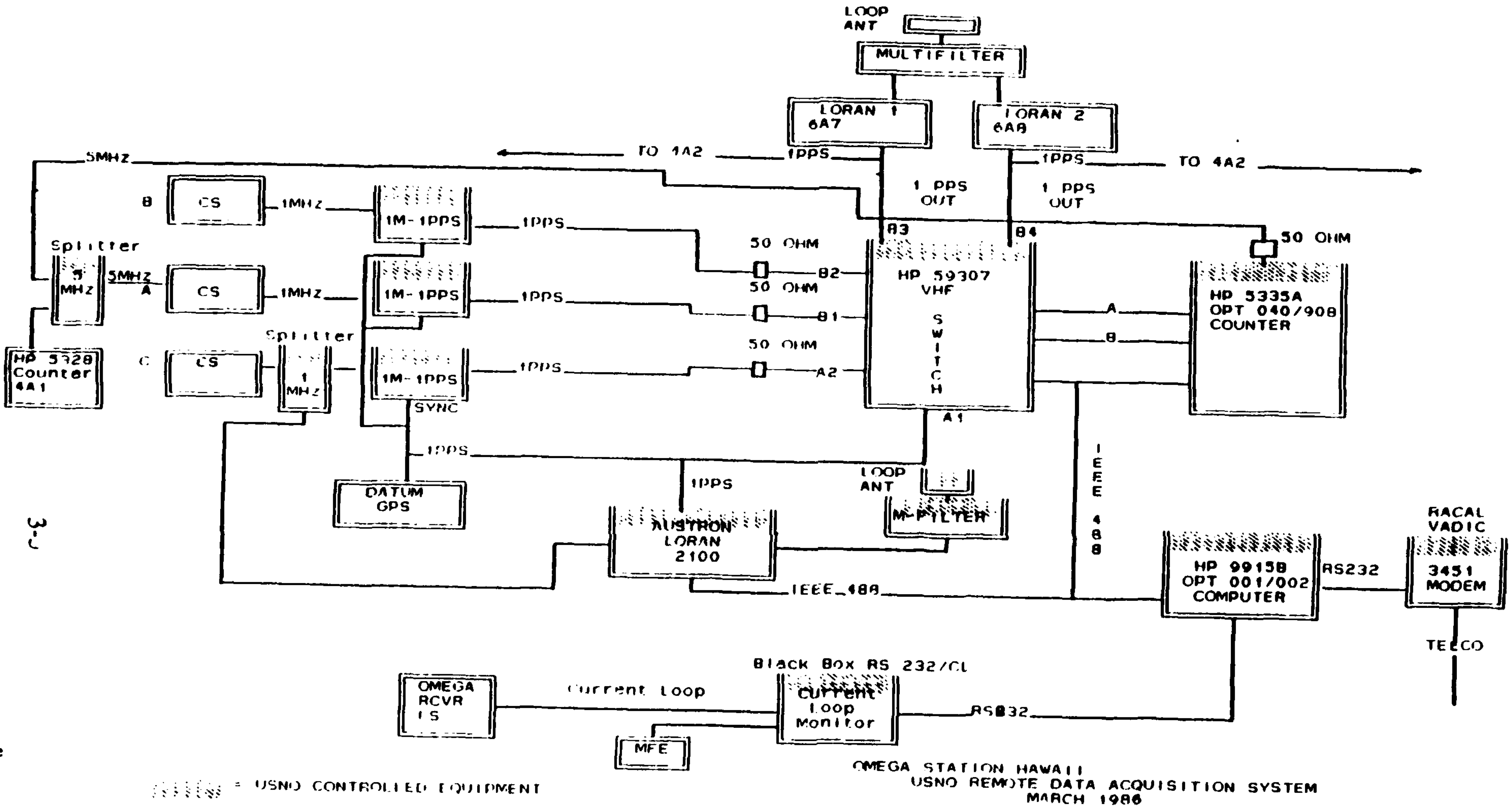

Figure 3.2-3 USNO Remote Data Acquisition System (OMSTA Hawaii)

```
---------------
47552           *
0               *
.999972641      *
.000024502      *
.015946753
.015946998
.999963657      *
.000015517      *
.015937764
.015937972
.999966471
.000018348
.015940531
.015940776
.399977464
.400029324
.415951522
.415951756
99800.3
-.00000249
---------------
47552.0416667   *
100             *
.999972601      *
.000024463      *
.015946627
.015946875
.99996366       *
.000015521      *
.01593768
.015937927
.999966476
.00001834
.015940503
.015940741
.399977467
.40002933
.415951475
.415951685
79700.3
.01594707
---------------
```

Figure 3.3-1 A Sample of PTTI data collected by USNO RDA System for Omega Station Norway

* These record fields are the direct inputs to the CSP

Table 3.3-1

Covariance Simulation RDAS Timing Measurements

(OMSTA Norway)

Record Field No.	Station Configuration Channel Description	Description of the Data Field
1	NA	Modified Julian Date (MJD) of the data being reported in this record*
2	NA	GMT Time of the Day*
3	A1-B1	GPS-CS017*
4	A1-B2	GPS-CS124*
5	A1-B3	GPS-LOR1
6	A1-B4	GPS-LOR2
7	A2-B1	CS486-CS017*
8	A2-B2	CS486-CS124*
9	A2-B4	CS486-LOR1
10	A2-B4	CS486-LOR2
11	A3-B1	OMSFOG-CS017
12	A3-B2	OMSFOG-CS124
13	A3-B3	OMSFOG-LOR1
14	A3-B4	OMSFOG-LOR2
15	NA	CLOCK-CS017
16	NA	CLOCK-CS124
17	NA	CLOCK-LOR1
18	NA	CLOCK-LOR2
19	NA	CS486-LORM
20	NA	CS486-LORX

*These record fields are the direct inputs to the CSP.

Table 3.3-2

Covariance Simulation RDAS Timing Measurements

(OMSTA Hawaii)

Record Field No.	Station Configuration Channel Description	Description of the Data Field
1	NA	Modified Julian Date (MJD) of the data being reported in this record*
2	NA	GMT Time of the Day*
3	A1-B1	GPS-CS554*
4	A1-B2	GPS-CS349*
5	A1-B3	GPS-LOR1
6	A1-B4	GPS-LOR2
7	A2-B1	CS529-CS554*
8	A2-B2	CS529-CS349*
9	A2-B4	CS529-LOR1
10	A2-B4	CS529-LOR2
11	A3-B1	OMSFOG-CS554
12	A3-B2	OMSFOG-CS349
13	A3-B3	OMSFOG-LOR1
14	A3-B4	OMSFOG-LOR2
15	NA	CLOCK-CS554
16	NA	CLOCK-CS349
17	NA	CLOCK-LOR1
18	NA	CLOCK-LOR2
19	NA	CS529-LORM
20	NA	CS529-LORX

*These record fields are the direct inputs to the CSP.

It should be noted that it is necessary to pre-process some of the data before it is used as a measurement in the CSP. Julian day and GMT time of day are extracted from the MJD field in the following manner:

47475 .2083333
47475 = Modified Julian Day
= 10 November 1988

.2083333 = GMT Time of the Day
= .2083333 x 24
= 0500 Hours

Additionally, it is necessary to convert the raw timing data to microseconds and decode it. The following algorithm is used to perform this conversion:

- If a measurement is less than 0.5 seconds, it is simply multiplied by 10^6 to obtain a phase (time) measurement in microseconds

- If a measurement is greater than or equal 0.5 seconds, then first 1 is subtracted from it, and then it is multiplied by 10^6.

For the specific timing data records examined within this report, each of the records were reviewed to identify any anomalies (e.g., data dropouts) due to the RDAS equipment problems. These anomalies were edited out of records to create records suitable for CSP processing.

A final note regarding Tables 3.3-1 and 3.3-2 is in order. Note that though OMSFOG data is available, it is not used in this study. The OMSFOG data contains the effects of corrections inserted by the current synchronization process. By using only the measurements obtained before the OMSFOGs, we are able to produce simulations which are independent of the current control process.

4. COVARIANCE SIMULATION PROGRAM

This section describes the Kalman filter developed to investigate cesium clock stability. The filter is designed to provide cesium phase and frequency offset estimates based upon GPS timing measurements. Section 4.1 discusses the models for the two primary physical elements in the model: the cesium clocks and the GPS receiver. Section 4.2 develops the filter model and Sections 4.3 and 4.4 discuss the various run options provided by the program.

The filter described here may be used as a tool to investigate hypothesized synchronization schemes that might incorporate GPS data. Theoretical questions that may be examined include questions such as how frequently must GPS data be processed to keep the cesium phase error at an acceptable level. The CSP was developed to provide the user the flexibility to examine different measurement sets and measurement update schedules. To set the stage for the filter discussion, a brief overview of key features of the cesium synchronization process is provided below.

Cesium frequency standards have excellent short term stability, but gradually drift so that after extended intervals their phase outputs will exceed tolerance limits. To maintain tolerance limits, some form of clock corrections must be used. Under the current control method, new system phase corrections for each station are derived and applied once a week. The major hindrance to more frequent corrections is the telecommunications burden associated with the collection of reciprocal path Omega readings. If we were to rely exclusively on GPS and cesium readings, more timely corrections might be feasible since all the measurements needed to derive corrections for a given station would be obtained at that station. Though numerous other implementation/quality assurance factors would have to be considered, we can explore some theoretical aspects of the problem.

4.1 CLOCK MODELS

4.1.1 Cesium Clocks

Cesium clocks are characterized by excellent short term stability. Once synchronized, such clocks are able to provide highly accurate time outputs for extended periods. Gradually, however,

errors in the time outputs increase to unacceptable levels; frequency errors integrate into phase errors and a slow growth in the phase offset errors appears. At such times some form of resynchronization, using new measurement data, is required.

To develop an estimation algorithm, some model of the growth of such errors must be considered. The model described here uses two clock states: phase offset and frequency offset, representing a bias and a drift in the cesium clock, respectively. Frequency offsets propagate in time into phase offsets, and random effects occurring at both the frequency and phase levels also corrupt the phase offset. The description provided here is based upon Reference 3.

The phase or time offset of a transmitter relative to UTC (in μsec) is given at time t_{n+1} by*

$$[\delta\phi]_{n+1} = [\delta\phi]_n + \Delta T[\delta f]_n + [w^{\phi}]_n \tag{4.1-1}$$

and

$$[\delta f\,]_{n+1} = [\delta f\,]_n + [w^f\,]_n \tag{4.1-2}$$

where

$\delta\phi$ = cesium phase offset in μsec,

δf = cesium frequency offset in μsec/day,

w^{ϕ} = zero-mean white noise sequence corrupting the time offset ($\delta\phi$) caused by uncorrelated fluctuations in cesium clock frequency,

w^f= zero-mean white noise sequence corrupting the time drift rate (δf) caused by uncorrelated fluctuations in cesium clock frequency-rate,

ΔT = discrete time step (1/2 day).

A block diagram representation of these equations is shown in Figure 4.1-1.

---

*The subscript n denotes the discrete time at which the phase offset is computed. Thus $[\delta\phi]_n$ = $\delta\phi(t_n)$ where $t_n(n=1,2,3,...)$ are the computational times separated by the discrete time step ΔT.

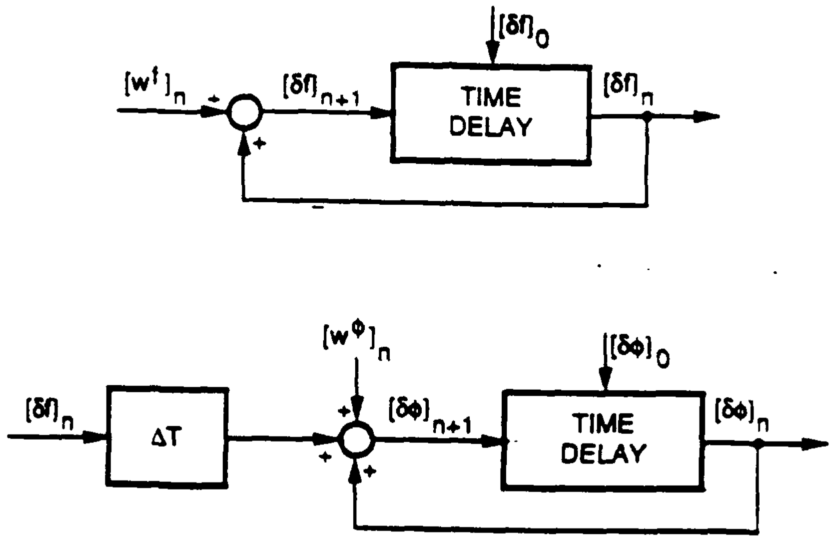

Figure 4.1-1 Covariance Simulation Cesium Clock Error Model

This model shows that any initial time drift rate (cesium frequency offset) will produce a corresponding time offset that grows linearly with time. Any random fluctuation in the cesium clock frequency, w^{ϕ}, results in a random walk timing error that grows in proportion to the square root of time. The RMS value of w^{ϕ} is taken in this study to be

$$\sigma_{w\phi} = 0.0189\ \mu\text{sec (or } \sigma^2_{w\phi} = 3.6 \times 10^{-4}\ \mu\text{sec}^2) .$$

The white sequence w^f is included in the clock error model to roughly approximate the long term random-walk-type behavior in the nominal time drift rate (cesium frequency offset) observed in empirical data. Each discrete jump in the cesium frequency offset of magnitude $\Delta\delta f$ occurring after an N day interval is approximated by a series of small jumps of magnitude $\Delta\delta f/2N$ occurring twice a day. The RMS value of w^f appropriate for this approximation is given by

$$\sigma_{wf} = \Delta\delta f/\sqrt{2N} .$$

For a worst-case jump of 0.3 μsec/day and a worst-case time interval of 15 days, the above equation yields

$$\sigma_{wf} = 0.055 \ \mu\text{sec/day (or } \sigma^2_{wf} = 0.3 \times 10^{-2} \ (\mu\text{sec/day})^2).$$

The values for both $\sigma_{w\phi}$ and σ_{wf} presented in this section are consistent with Reference 3.

4.1.2 GPS Receiver/GPS Time Outputs

The receiver employed at the Omega sites is a DATUM Model 9390 GPS Time/Frequency monitor. In the time and frequency monitoring mode of operation, the receiver outputs time pulses synchronized to UTC, and measures time and frequency inputs from an external time and frequency source. In contrast to the short term stability provided by stand-alone cesiums, GPS receiver time outputs are characterized by excellent long-term stability. GPS receiver time outputs are derived via filtering of pseudorange measurements, with the resulting time accuracy dependent on several error sources. GPS time errors are typically modeled by biases and additive white noise.

In the context of this effort, a model of GPS time output errors is required to develop a model of the GPS/cesium difference measurements. Specifically, the uncertainty in the GPS/cesium measurements will be a function of the uncertainty in the GPS time data and the inherent uncertainties in the measurement process itself. In this study, the error in the GPS measurements is considered as a white noise sequence with standard deviation

$$\sigma_G = 0.05 \ (\mu\text{sec}) \ (\text{or } \sigma_G{}^2 = 0.0025 \ \mu\text{sec}^2).$$

This value has been selected on the basis of empirical data.

Note that no attempt has been made to model biases in the GPS time outputs. The errors are assumed to be zero mean white noise characterized by the variance given above. This is not a severe limitation. Owing to the long term stability of GPS time, infrequent corrections of the outputs might keep any biases at acceptable levels. The consideration of techniques for removing biases from the GPS timing outputs is beyond the scope of the current effort.

4.2 KALMAN FILTER ALGORITHM

This section provides a discussion of a Kalman filter developed to estimate time errors in cesium clocks using GPS-based time measurements. A basic discussion of the algorithm is provided in Section 4.2.1. Sections 4.2.2 and 4.2.3 describe the user provided CSP inputs to the model. The two input parameter files required to run the CSP, PARM.IN and KFTABL.IN, are covered in Sections 4.2.2 and 4.2.3, respectively.

4.2.1 Filter Algorithm

A six state Kalman filter was developed to provide estimates of the phase and frequency offsets for each of the three cesiums using available measurement data. The specification of the filter is straightforward once the system dynamics and observation model have been defined. A discussion of the system dynamics and the observation model used here are presented in Sections 4.2.1.1 and 4.2.1.2, respectively. For convenience, the standard set of Kalman filter equations (Reference 4) are summarized in Table 4.2-1. The two major steps in this process, the propagation step and the measurement update step, are discussed in subsection 4.2.1.3 and 4.2.1.4, respectively.

TABLE 4.2-1

KALMAN FILTER ALGORITHM

Optimal Estimate	
$\hat{x}^-_n = \Phi \hat{x}^+_{n-1}$	Propagation
$\hat{x}^+_n = \hat{x}^-_n + K_n [z_n - H_n \hat{x}^-_n]$	Update
$K_n = P^-_n H^T_n [H_n P^-_n H^T_n + R_n]^{-1}$	Weighting
Estimation Error Covariance	
$P^-_n = \Phi P^+_{n-1} \Phi^T + Q_{n-1}$	Propagation
$P^+_n = [I - K_n H_n] P^-_n [I - K_n H_n]^T + K_n R_n K_n^T$	Update

The main objective of the filter is to provide an estimate, denoted $\delta\hat{\phi}$, of the actual phase offset $\delta\phi$. The state estimation error $\tilde{x}_n$ at time t_n is defined as the difference between the optimal estimate $\hat{x}_n$ and the actual system state x_n, i.e,

$$\tilde{x}_n = \hat{x}_n - x_n .$$

Letting E denote the expected value operator, the error covariance matrix P is defined as

$$P_n = E[\tilde{x}_n \tilde{x}_n^T] .$$

Note when n=0 this represents the initial covariance.

The remaining matrices appearing in the algorithm are process noise defined as

$$Q = E[w_n w^T_n]$$

and measurement noise defined as

$$R = E[v_n v^T_n].$$

These matrices model the various error processes that affect system synchronization and must be specified prior to estimating the system state vector x_n. Q and P_0 depend on the calibration and performance characteristics of the cesium frequency standards. The measurement covariance matrix R depends on the magnitude of the uncorrelated measurement errors.

4.2.1.1 *System Dynamics*

The system states are defined to be the phase and frequency offsets for each of the three cesiums: online, primary and secondary. The system state is written as

$$x = [\delta\phi_1, \delta f_1, \delta\phi_2, \delta f_2, \delta\phi_3, \delta f_3]^T$$

where the indices 1, 2 and 3 correspond to the online, secondary and primary cesiums for OMSTA Norway. For OMSTA Hawaii, the index 2 corresponds to the primary and the index 3 to the secondary. This convention corresponds to the order of the measurements in the data file. For clarity, the remainder of the section follows the Norway convention.

The state propagation equation has the form

$$x_n = \Phi x_{n-1} + w_{n-1}$$

The form of the state transition matrix follows from the discussion in Section 4.1.1, and is given by

$$\Phi = \begin{bmatrix} A & 0 & 0 \\ 0 & A & 0 \\ 0 & 0 & A \end{bmatrix}$$

where A is a two-by-two matrix of the form

$$A = \begin{bmatrix} 1 & \Delta T \\ 0 & 1 \end{bmatrix}$$

The driving white noise sequence w also follows from Section 4.1.1,

$$w = [w^{\phi}_1, w^f_1, w^{\phi}_2, w^f_2, w^{\phi}_3, w^f_3]^T .$$

4.2.1.2 *Observation Model*

The observation model relates the system states to the measurement values. In the current application there are two general classes of measurements with a total of five different measurement types. The GPS/cesium phase difference measurements are of three types: GPS/online, GPS/secondary and GPS/primary. The cesium/cesium phase difference measurements are of two types: online/secondary and online/primary. The model for one type of each class will be discussed here; the remaining types follow by analogy.

It is important to point out that the displayed value of phase offset shown in this report, in an absolute sense, has no particular relationship to the time error of the current Omega system. Synchronization errors such as shown in Figure 4.2-1 and other figures in this report are obtained from the readings of the cesium outputs, before the OMSFOG corrections are applied. Thus, the values of the displayed phase measurements represent the "coarse" frequency offset of the cesium, propagated by the time since the USNO RDAS equipment initialization. The other contributors to the displayed phase offsets can be the equipment resets or failures with the resultant timing jumps. If a decision were made to build a synchronization system critically dependent upon the RDAS equipment, special operational procedures and redundant equipment would be employed at the OMSTAs. The goal of this analysis is to make an initial estimate of the system complexity and to provide a method to determine the required measurements/correction/incorporation schedule to achieve a required performance level. Therefore, for the purposes of this study, the behavior of the USNO RDAS measurements, their variation from time to time, is of the most importance. The absolute value of the displayed timing data has no real significance.

The general linear relation between the state and the measurement is given by,

$$z = Hx + v.$$

In this equation, z is the actual measurement, H is the observation vector relating the state and the measurement, and v is the observation error, assumed to be uncorrelated. The covariance of v is called the measurement noise matrix (the R matrix).

For the GPS/cesium difference measurements, in particular the GPS/online cesium measurements, the model is as follows,

$$z = -\delta\phi + v_{GC},$$

where z is the measured GPS/online cesium phase difference, and $\delta\phi$ is the phase offset in the online cesium. Comparing with the general linear relation given above and state definition, it is evident that

$$H = [-1, 0, 0, 0, 0, 0] .$$

The term v_{GC} represents the combined error in the GPS receiver time and the error inherent in the measurement process, that is,

$$v_{GC} = v_G + v_{GCM} ,$$

where

v_G = error in GPS time outputs

v_{GCM} = error induced by the GPS/cesium measurement process.

The error v_{GCM} may be further specified as the sum of the error in measuring the GPS receiver time outputs (v_{GM}) and the error in measuring the online cesium time outputs (v_{C1}), such that

$$v_{GC} = v_G + v_{GM} + v_{C1} .$$

Assuming all errors are uncorrelated, it follows that

$$\sigma^2_{GC} = \sigma^2_G + \sigma^2_{GM} + \sigma^2_{C1} .$$

Based on experimental data and experience, we can select representative values for these variances. The measurement noise variance for the GPS time estimates is set at 0.0025 μsec^2 (or a standard deviation of 0.05 μsec). The value for σ^2_{GM} can be assumed to be negligible in comparison to σ^2_G. The value for σ^2_{C1} is also negligible with respect to σ^2_G, but is included here since it is relevant for the cesium/cesium measurement processes. Under these assumptions, σ_{GC} takes the form

$$\sigma^2_{GC} = \sigma^2_G + \sigma^2_{C1} \approx \sigma^2_G = 0.0025\ \mu\text{sec}^2 .$$

The reasonableness of this value (σ_{GC} = 0.05 μsec) may be qualitatively verified by examining Figure 4.2-1. This figure shows a plot of the GPS/cesium measurement for the online cesium at OMSTA Norway for a 9 day period. The assumed standard 0.05 μsec deviation for the measurements is shown via the dashed lines on the plot. Better than 55% of the data points fall within these bounds. The assumed variance is a reasonable starting point for this model.

For the cesium/cesium difference measurements, specifically the online/primary cesium, the model is as follows:

$$z \quad = \; + \, \delta\phi_1 - \delta\phi_3 + v_{C13}$$

where z is the measured online/primary cesium phase difference, $\delta\phi_1$ and $\delta\phi_3$ are the online and primary phase offsets, respectively, and v_{C13} is the error induced by the measurement process. The subscripts 1 and 3 reference the online and primary clocks, respectively. The statistics of v_{C13} depend on several factors including characteristics of the hardware devices involved in the measurement process. Lacking precise information, the error in the difference measurement is assumed to be the sum of the errors in the measurement of each clock. Specifically,

$$v_{C13} = v_{C1} + v_{C3}$$

and, assuming the errors are uncorrelated,

$$\sigma^2_{C13} = \sigma^2_{C1} + \sigma^2_{C3} \, .$$

4.2.1.3 ***Time Propagation***

In between measurements the state estimates and the covariance matrix propagate as specified by the system dynamics. The state estimate propagates as

$$\hat{x}(t_k) = \Phi \, \hat{x}(t_{k-1}),$$

or, more specifically for our case,

$$\delta\hat{\phi}(t_k) = \delta\hat{\phi}(t_{k-1}) + \Delta T \, \delta\hat{f}(t_{k-1}) \text{ , and}$$

$$\delta\hat{f}(t_k) = \delta\hat{f}(t_{k-1}).$$

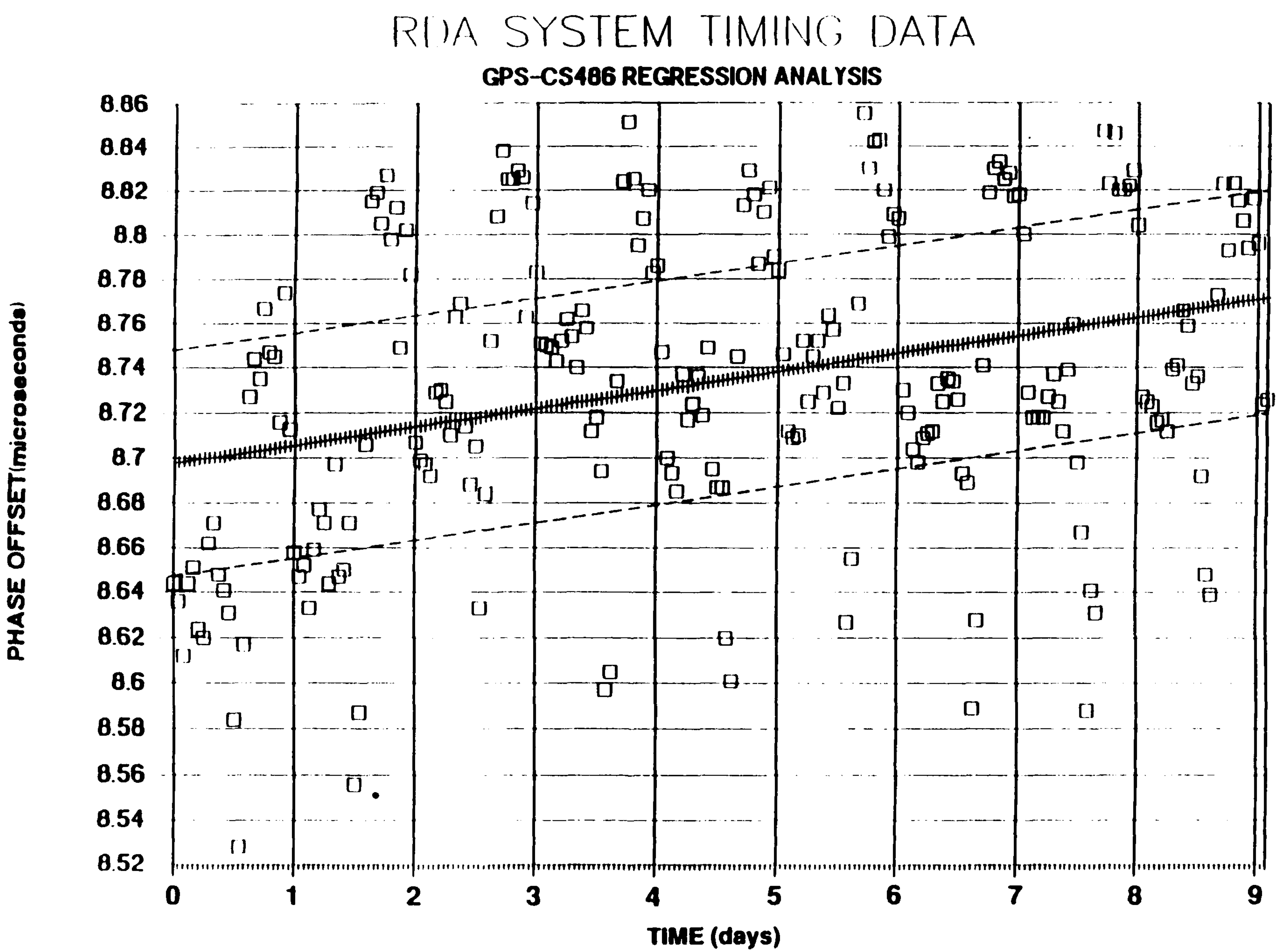

Figure 4.2-1 Measurement Phase Offsets (Norway)

The error covariance must also be propagated forward in time according to the dynamics equations. In general,

$$P^{-}(t_k) = \Phi \, P^{+}(t_{k-1}) \, \Phi^{T} + Q(t_{k-1}).$$

The growth in the error covariance is seen to be comprised of a deterministic part, $\Phi P^{+} \Phi^{T}$, and a term accounting for random disturbance, the process noise matrix Q. The process noise matrix Q follows from the cesium clock model. Q is a diagonal matrix with diagonal elements, given by:

$$Q_{11} = Q_{33} = Q_{55} = \sigma^2_{w\phi} \ ,$$

$$Q_{22} = Q_{44} = Q_{66} = \sigma^2_{wf} \ .$$

4.2.1.4 *Measurements and Measurement Update*

When measurement data becomes available it may be used to update the state estimates and covariance matrix. The Kalman filter processing algorithm provides the means to incorporate these measurements in a statistically optimal sense. The updated state estimate is equal to the a priori estimate plus the product of the Kalman gain and the measurement residual. i.e.,

$$\hat{x}^{+} = \hat{x}^{-} + K\,(z - H\,\hat{x}^{-})$$

where.

K = Kalman gain,
H = observation vector,
z = measurement,
$z - H\hat{x}^{-}$ = predicted measurement residual,
$\hat{x}^{+}$ = measurement updated estimate (a posteriori estimate), and
$\hat{x}^{-}$ = propagated estimate (a priori estimate).

The optimal Kalman gain is given by

$$K = PH^{T}(HPH^{T} + R)^{-1}$$

where

R = measurement noise matrix,

P = covariance matrix, and

$HPH^T + R$ = residual variance.

The uncertainty in the estimate, expressed in P, is reduced by the incorporation of the new measurement data

$$P^+ = P^- - KHP^-.$$

Within the code, this measurement update equation is implemented in the algebraically equivalent, but numerically more stable, form

$$P^+ = (I - KH)\, P^-(I - KH)^T + KRK^T.$$

In this section we have discussed a specific Kalman filter which defines the estimation process required for this study. In the following sections we will detail the CSP software file structure which allows the user to define the parameters of the estimation process. The user must define the measurement and process noise parameters and the initial state and covariance estimate for each desired estimate. These parameters are defined in a file called PARM.IN, which is discussed in Section 4.2.2 below. The user must also define the measurement set to be used, the time interval between measurements and define the filter execution and output process. These are defined in a file called KFTABL.IN, which is discussed in Section 4.2.3.

4.2.2 Defining System Parameters (PARM.IN)

In this section a discussion of the specific filter parameters is provided. In addition, the specific parameter values used in the test runs are provided. The parameters are related to the CSP parameter input file PARM.IN; through this file the program user may accept default values or adjust the parameters from their predefined values. The User's Guide (Reference 1) provides a detailed discussion of this file.

The measurement noise and process noise parameters, along with the initial state and covariance estimates, will determine the filter's behavior. The process noise and measurement noise are defined on the basis of general physical considerations. A general description of the PARM.IN file and a sample PARM.IN file used for the Norway simulation runs are shown in Table 4.2-2. The various elements to this table are discussed in the following subsections.

4.2.2.1 ***Measurement Noise Matrix (R)***

The measurement error variances for the five types of difference measurements being considered are derived from assumed values for the each element. For example, if the measurement is the time difference between the GPS and primary cesium clock times then the measurement error variance value is determined as

$$\sigma^2 = \sigma^2{}_G + \sigma^2{}_{C3} .$$

Appropriate measurement noise variances for the other measurement types are formed in a similar fashion. The assumed error variances for the different timing devices are:

$\sigma^2{}_G$ = 0.0025 μsec^2 GPS,
$\sigma^2{}_{C1}$ = 0.000049 μsec^2 online cesium,
$\sigma^2{}_{C2}$ = 0.0001 μsec^2 secondary cesium, and
$\sigma^2{}_{C3}$ = 0.000064 μsec^2 primary cesium.

The value of $\sigma^2{}_G$ has been established as discussed in Section 4.2.1.2. Values for $\sigma^2{}_C$ have been chosen to represent a range of uncertainties that can be reasonably expected, but more importantly, to demonstrate filter performance under varying conditions. The parameters of measurement noise variances are set by the program user through the PARM.IN file parameters SIG. Specifically,

'SIG = ', SIG GPS, SIG ONL, SIG SEC, SIG PRI

where,

SIG GPS = standard deviation in GPS time measurement errors (μsec),
SIG ONL = standard deviation in online cesium measurement errors (μsec),
SIG PRI = standard deviation in primary cesium measurement errors (μsec), and
SIG SEC = standard deviation in secondary cesium measurement errors (μsec).

The values shown in Table 4.2-2 for the OMSTA Norway simulation correspond to the numerical values detailed above.

TABLE 4.2-2

PARAMETER FILE CONTENTS

RECORD	NAME	VALUE (UNITS)
1	CLK	Initial time offset estimate (μsec), initial frequency estimate (μsec/day).
2	TIME	Time interval parameter used in calculation of Q matrix elements (days).
3	COV	Mean square uncertainty in phase offset estimate $(\mu\text{sec})^2$, mean square uncertainty in frequency offset estimate $(\mu\text{sec/day})^2$.
4	ERR	Largest discrete jump in cesium frequency offset (μsec/day), corresponding measurement time interval (days).
5	Q COV	Mean square frequency fluctuation $(\mu\text{sec})^2$, mean square frequency-rate variance $(\mu\text{sec/day})^2$.
6	SIG	Root mean square time measurement error (μsec), GPS or cesium clocks

```
'CLK   = ',0.3570, 0.011461, -0.7380, 0.119371, 1.21, -0.050453
'TIME  = ',0.5, 0.5, 0.5
'COV   = ',0.0001, 0.0016, 0.000225, 0.0016, 0.0000, 0.0016
'ERR   = ',0.03, 15.0, 0.03, 15.0, 0.03, 15.0
'QCOV  = ',0.00036, 0.0, 0.00036, 0.0, 0.00036, 0.0
'SIG   = ',0.050, 0.007, 0.010, 0.008
```

4.2.2.2 *Process Noise Matrix (Q)*

The process noise matrix Q is intended to reflect uncertainties in the form of the system propagation equations (e.g. unmodeled states, injection of random noise). The form of the Q matrix follows from the discussion of the cesium clock physics briefly considered in Section 4.1.1. The Q matrix is defined to be diagonal with the diagonal elements Q11, Q33, Q55 corresponding to $\sigma^2_{w\phi}$, and Q22, Q44, Q66 corresponding to σ^2_{wf}. The program user may adjust these process noise tuning parameters through the PARM.IN file parameter Q COV.

Q COV = 'Q11, Q22, Q33, Q44, Q55, Q66'

where,

Q11 = online clock frequency noise variance, and

Q22 = online clock frequency rate noise variance.

The pairs Q33, Q44 and Q55, Q66 are similarly defined for the secondary and primary clocks respectively.

The user may also specify the Q22, Q44, Q66 terms through the use of the PARM.IN file parameter ERR. This allows those elements to be defined according to the equation for σ_{wf} provided in Section 4.4.1, that is

$$\sigma_{wf} = \Delta\delta f / \sqrt{N/TIME}$$

The elements of ERR are

ERR = 'ERR1, ERR2, ERR3, ERR4, ERR5, ERR6'

where,

ERR1 = $\Delta\delta$f for online cesium, and

ERR2 = N days for online cesium.

The TIME parameter is used to designate the interval between discrete jumps in the frequency offsets. Following Reference 3, it is assumed such jumps occur "twice a day". The nominal value for TIME is, thus, 1/2 day. The remaining parameter ERR3, ERR4 and ERR5, ERR6 are similarly defined for the secondary and primary clocks. (NOTE: If this method is used to define Q22, Q44

and Q66, then these terms must be set to zero in Q COV, that is Q COV must have the form Q COV = 'Q11 , 0 , Q33, 0, Q55, 0 ').

4.2.2.3 *Initial Error Covariance Matrix (P_0)*

In typical filter applications, the initial state of a system is known only roughly; a fairly high degree of uncertainty may exist. The diagonal elements of the initial covariance matrix (P_0) should be chosen to reflect this uncertainty. The physics of the problem, as well as experimentation, lead the filter designer to choose appropriate values. The covariance simulation tool allows the user to select these initial variances. Ideally, the uncertainties selected should reflect the uncertainty in the initial conditions. Large variances should be selected if there is a high degree of uncertainty in the initial estimate to help ensure that the filter will converge rapidly. Small variances may be used if the initial state is known with a high degree of certainty, to avoid overshoots and oscillations. Selecting variances that are too small will increase the time required for the filter to converge. Typically, a conservative filter design will use large variances as default values but allow the operator to override these defaults if initial data is known to be highly accurate.

The program user may select these values through the PARM.IN file parameter COV. Specifically,

COV = 'P11, P22, P33, P44, P55, P66'

where,

P11 = Initial uncertainty (variance) in online clock phase offset estimate

P22 = Initial uncertainty (variance) in online clock frequency offset estimate

the pairs P33, P44 and P55, P66 are similarly defined for the secondary and primary clocks.

For the test cases presented in Section 5, the diagonal elements of the initial error covariance matrix were set to 100 ns^2 (online cesium), 0 ns^2 (primary cesium), and 150 ns^2 (secondary cesium). The initial variances corresponding to the frequency offset states were set to 1600 $(ns/day)^2$ for each of the three clocks. This particular selection of values is somewhat arbitrary and is intended in part to examine the behavior of the filter.

-     4.2.2.4 ***Initial State Estimate*** $(\hat{x}_0)$

Since one of the primary purposes of this study is to examine the steady state behavior of the filter, and the available data records are relatively short, it is desirable to begin with initial state estimates approximating the actual state. For purposes of testing the performance of the filter, the initial filter estimates were derived by direct processing of the data. That is, measurement data was examined offline to determine suitable initial estimates for the phase offset and frequency offset for each of the three clocks. The best performance is achieved if the initial estimate and the initial covariance matrix are consistent.

The user may adjust the initial state estimates through the PARM.IN file parameter CLK. Specifically,

CLK = 'PH1, FR1, PH2, FR2, PH3, FR3'

where,

PH1 = Initial phase offset estimate for online clock,

FR1 = Initial frequency offset estimate for online clock.

Likewise the pairs PH2, FR2 and PH3, FR3 are similarly defined for the secondary and primary clocks.

4.2.3 **Defining System Parameters (KFTABL.IN)**

The second major input file involved in the CSP is called "KFTABL.IN". This file is used to control the simulation process. It determines which measurement set is used, the time interval between measurements, and the output and termination functions. There are four types of events used by the CSP: update (UPDT), propagate (PROP), USER, and STOP. The operator specifies parameters for each of these events. During the update event the covariance matrix is updated to incorporate sensor measurements. The propagate event allows the covariance to propagate through a time interval. The USER event exits the Kalman filter program and enters the output routines. Finally, the STOP event terminates the simulation. A sample event file is shown in Figure 4.2-2. This file shows three GPS/cesium measurements processed during a 31-day time period. The filter process propagates estimates on a half-day basis, performing an update every three days.

```
PROP(CNST,STAT) FROM 0.0 TO 31.0 BY 0.5
UPDT(VARY,GPS1,STAT) FROM 0.0 TO 31.0 BY 3.0
UPDT(VARY,GPS2,STAT) FROM 0.0 TO 31.0 BY 3.0
UPDT(VARY,GPS3,STAT) FROM 0.0 TO 31.0 BY 3.0
USER(LTUS) FROM 0.0 TO 31.0 BY 0.5
STOP AT 31.0
```

Figure 4.2-2 Sample Event File (KFTABL.IN)

Events are scheduled by order of time sequence labeling and by order of appearance in the event file. In other words, if several events are scheduled, they will be executed in the order as they appear in the event file. The sole exception is the PROP event from t_n to t_{n+1} which is defined at t_n. It is executed after all other events at t_n and before any other event at t_{n+1}.

The UPDT event identifies the measurement set used in the CSP. The first argument in the update call is always VARY, indicating a varying measurement matrix. The second argument defines the measurement set. Any single update can consist of five measurements as shown in Table 4.2-3. The last argument is always STAT, forcing the Kalman filter to propagate the estimated phase and frequency offset errors to the next sample time point.

The USER event is a general purpose exit from the CSP to perform auxiliary computations on the covariance analysis in progress. In the CSP it is used to generate a LOTUS output file. This plot file is a list of records, each one containing time, phase estimate, frequency estimate and RMS uncertainties in the estimates A more thorough discussion of the filter ouputs and LOTUS output file format is contained in Sections 4.3 and 4.4.

TABLE 4.2-3

RDAS MEASUREMENT SET

UPDT	MEASUREMENT DESCRIPTION
GPS1	Difference between GPS and on-line cesium
GPS2	Difference between GPS and secondary* cesium
GPS3	Difference between GPS and primary* cesium
CLK1	Difference between on-line and secondary* cesiums
CLK2	Difference between on-line and primary* cesiums

The STOP event provides the program the ability to terminate normally without hitting the end of the file marker. No records after the first STOP are executed, permitting the user to modify or debug a simulation easily.

4.3 SIMULATION OUTPUTS

This section describes the outputs provided by the CSP. The reader is referred to the User's Guide (Reference 1) for additional details on the procedures required to generate these outputs. The primary outputs provided by the program are:

- State Estimates : estimated phase and frequency offsets
- Filter Indicated RMS Errors (i.e., square root of filter variances)
- Phase Offset "Residuals"

* Primary and secondary cesium measurements are reversed in Hawaii RDAS timing data.

The main outputs of the filter are the phase and frequency offset estimates. Each time a measurement is provided to the filter these values are updated to reflect the new data. In the various scenarios examined in Chapter 5 and the addendum, the interval at which measurements are provided to the filter is varied between 0.5 days and 7 days. Between these updates the estimates are maintained by propagation according to the state transition matrix. For the Norway scenarios the interval between propagation steps is 0.5 days, while for the Hawaii scenarios this interval is 1.0 day (the reason for this difference is discussed in Section 5.2).

The diagonal elements of the error covariance matrix P provide an indication of the filter's determination of the error in the provided estimate. Small variances indicate the filter is confident of the state estimate. For convenience, the filter indicated RMS errors (i.e. the square root of the variances) are provided as outputs. The filter indicated RMS errors for a particular phase offset estimate will be at a minimum just after a measurement has been incorporated. Between measurements this uncertainty will grow for two reasons. The uncertainties in the frequency estimate will propagate into uncertainties in the phase offset estimates. The uncertainty will also increase due to the presence of random disturbances modelled in the process noise matrix Q.

One of the major aims of good filter design is to ensure that filter-indicated RMS errors are consistent with the actual errors in the state estimates. Ideally, one would like "truth" data during the filter's testing period to verify performance. In this case we would hope that the filter's estimates of the states (phase and frequency offsets), and of the RMS errors in these states, would be consistent. That is, the actual error in the state estimate should be roughly equivalent to the corresponding diagonal element of the error covariance matrix. As with most filter applications the "truth" data required to compute the actual error in the state estimate is not available. Therefore, to gain some insight into the performance of the filter, phase offset "residuals" are also provided as an output by the CSP. The phase offset residual for a clock is defined here as the difference between the measured GPS/cesium phase difference and the best available CSP estimate of that cesium phase offset. The best available estimates between measurement updates are the propagated phase estimates. Further, at a measurement update time, two estimates are available: an a priori estimate, propagated forward from the previous cycle, and an a posteriori, measurement updated estimate. This latter quantity reflects the incorporation of the new measurement data and is therefore a better estimate than the a priori estimate. In forming the residuals at the measurement update times, the a posteriori, measurement updated, estimate will be used. The

phase offset residuals defined here are provided for analysis purposes only and are not used by the filter in determining the estimates. The CSP computes these phase offset residuals at each propagation step (set at 0.5 days for Norway and 1.0 days for Hawaii).

This definition is provided to avoid confusion with the term "predicted residual" commonly used in filter applications. The term predicted residual refers to the quantity $z - H\hat{x}^-$ defined in Section 4.2.1.4 and represents the difference between an actual measurement used by the filter and the filter's predicted measurement based on the a priori state estimate. The predicted residual is defined only at the measurement update steps. Thus, if the measurement update interval is 5 days, the predicted residual is computed every 5 days. Note also in the case where the measurement used by the filter is a cesium/cesium difference measurement, the predicted residual, $z - H\hat{x}^-$, is a qualitatively different quantity than the phase offset residual defined in the previous paragraph. The predicted residuals will not be shown in this report, instead, the "phase offset residual" as defined above will be selected.

4.4 LOTUS OUTPUT FILE

This section discusses the actual file containing the various filter outputs. A single run of a CSP results in a generation of LOTUS output file. At the beginning of the filter execution, the user is asked to specify the file name that will be associated with the output LOTUS file. A brief discussion of the LOTUS file is provided to familiarize the user with the filter applications.

The LOTUS output file is used to generate a set of simulation plots that describe the state of cesium phase and frequency offsets, plus the accuracy of the estimation process. Table 4.4-1 defines the data elements in the output file for OMSTA Norway. Figure 4.4-1 contains an example of a LOTUS worksheet generated from one of the LOTUS output files.

The data is divided into three major categories. Worksheet columns A and B identify the Julian day and day counter from the beginning of the RDAS timing data collection process. The value of the Julian day changes only with next measurement update event. Thus, an example shown in Figure 4.4-1 can be recognized as a 3-day update rate configuration run. In other words, the measurements get incorporated into CSP at 3 day intervals: 0, 3, 6, 9, etc. Columns C through H contain CSP state estimates: online clock phase offset estimate, online clock frequency offset

estimates and offline clocks respective state estimates. Note that the order of the clock data (i.e., online, secondary and primary) is controlled by the format sequence of input (NORWAY.DAT) file (refer to Section 3.3 of this report). Columns I through N contain uncertainties (1σ) of the state variables contained in columns C through H. The order of the RMS values corresponds to the order of the state variables. Finally, columns O through S contain measurement residuals. Columns containing residuals of measurements not used in the present configuration run are set to zero.

TABLE 4.4-1
LOTUS OUTPUT DATA FILE CONTENTS
(NORWAY)

ELEMENT	CONTENT
A	Data Point Modified Julian Date
B	Data Point Time
C	Phase Offset - Online Cesium Clock
D	Frequency Offset - Online Cesium Clock
E	Phase Offset - Primary Cesium
F	Frequency Offset - Primary Cesium
G	Phase Offset - Secondary Cesium
H	Frequency Offset - Secondary Cesium
I	Standard Deviation - Element C above
J	" " - Element D above
K	" " - Element E above
L	" " - Element F above
M	" " - Element G above
N	" " - Element H above
O	GPS - Online Cesium Measurement Residual
P	GPS - Secondary Cesium Measurement Residual
Q	GPS - Primary Cesium Measurement Residual
R	Online - Secondary Cesium Measurement Residual
S	Online - Primary Cesium Measurement Residual

A1: 47596 MENU

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	A	B	C	D	E	F	G	H
1	47596	0	-8.90045	0.01019	-63.9048	0.11755	-24.4203	-0.06232
2	47596	0.5	-8.89536	0.01019	-63.8460	0.11755	-24.4515	-0.06232
3	47596	1	-8.89026	0.01019	-63.7872	0.11755	-24.4827	-0.06232
4	47596	1.5	-8.88517	0.01019	-63.7284	0.11755	-24.5138	-0.06232
5	47596	2	-8.88007	0.01019	-63.6697	0.11755	-24.5450	-0.06232
6	47596	2.5	-8.87498	0.01019	-63.6109	0.11755	-24.5761	-0.06232
7	47599	3	-8.72369	0.05323	28.51411	43.43991	-26.6744	-0.67432
8	47599	3.5	-8.69708	0.05323	50.23407	43.43991	-27.0115	-0.67432
9	47599	4	-8.67047	0.05323	71.95402	43.43991	-27.3487	-0.67432
10	47599	4.5	-8.64385	0.05323	93.67398	43.43991	-27.6859	-0.67432
11	47599	5	-8.61724	0.05323	115.3939	43.43991	-28.0230	-0.67432
12	47599	5.5	-8.59062	0.05323	137.1138	43.43991	-28.3602	-0.67432
13	47602	6	-8.67999	0.03241	35.39664	-4.08099	-27.3883	-0.4402
14	47602	6.5	-8.66379	0.03241	33.35614	-4.08099	-27.6084	-0.4402
15	47602	7	-8.64758	0.03241	31.31565	-4.08099	-27.8285	-0.4402
16	47602	7.5	-8.63138	0.03241	29.27515	-4.08099	-28.0486	-0.4402
17	47602	8	-8.61518	0.03241	27.23466	-4.08099	-28.2687	-0.4402
18	47602	8.5	-8.59897	0.03241	25.19416	-4.08099	-28.4888	-0.4402
19	47605	9	-8.72544	0.00974	32.82698	-0.3704	-27.6606	-0.27409
20	47605	9.5	-8.72057	0.00974	32.64178	-0.3704	-27.7977	-0.27409

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Figure 4.4-1 Sample Worksheet Generated from LOTUS.OUT File

MENU

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Global Insert Delete Column Erase Titles Window Status Page Learn

	I	J	K	L	M	N	O	P
1	0.00981	0.04	0.01437	0.04	0	0.04	-0.26809	-104.602
2	0.02926	0.04037	0.03109	0.06782	0.02757	0.04037	-0.26809	-104.602
3	0.04923	0.04074	0.05724	0.08718	0.04824	0.04074	-0.26809	-104.602
4	0.06938	0.04111	0.09293	0.10296	0.06868	0.04111	-0.26809	-104.602
5	0.08967	0.04147	0.13619	0.11662	0.08913	0.04147	-0.26809	-104.602
6	0.1101	0.04183	0.18576	0.12884	0.10966	0.04183	-0.26809	-104.602
7	0.0467	0.02213	0.04898	0.08535	0.04669	0.02198	-0.16761	-96.0366
8	0.05749	0.0228	0.07555	0.10141	0.0575	0.02266	-0.16761	-96.0366
9	0.06843	0.02345	0.1158	0.11526	0.06842	0.02331	-0.16761	-96.0366
10	0.07954	0.02408	0.16433	0.12761	0.0795	0.02394	-0.16761	-96.0366
11	0.09085	0.02469	0.21907	0.13887	0.09077	0.02456	-0.16761	-96.0366
12	0.10236	0.02529	0.27906	0.14928	0.10224	0.02517	-0.16761	-96.0366
13	0.0458	0.01783	0.0495	0.09021	0.04579	0.01776	0.13827	126.0512
14	0.05398	0.01865	0.07608	0.10554	0.05395	0.01859	0.13827	126.0512
15	0.06242	0.01944	0.11809	0.1189	0.06237	0.01938	0.13827	126.0512
16	0.07113	0.0202	0.16858	0.13091	0.07105	0.02013	0.13827	126.0512
17	0.08013	0.02093	0.2252	0.14191	0.08002	0.02087	0.13827	126.0512
18	0.0894	0.02163	0.28693	0.15211	0.08926	0.02157	0.13827	126.0512
19	0.04463	0.01735	0.04953	0.09023	0.04462	0.01733	0.17911	-9.86731
20	0.05238	0.0182	0.07609	0.10555	0.05236	0.01818	0.17911	-9.86731

Figure 4.4-1 (con't) Elements I through P of the Sample Worksheet

MENU

Worksheet Range Copy Move File Print Graph Data System Add-In Quit
Global Insert Delete Column Erase Titles Window Status Page Learn

	Q	R	S	T	U	V	W	X
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2	2.33862	0	0					
3	2.33862	0	0					
4	2.33862	0	0					
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6	2.33862	0	0					
7	2.37166	0	0					
8	2.37166	0	0					
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11	2.37166	0	0					
12	2.37166	0	0					
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14	-1.56137	0	0					
15	-1.56137	0	0					
16	-1.56137	0	0					
17	-1.56137	0	0					
18	-1.56137	0	0					
19	-1.31694	0	0					
20	-1.31694	0	0					

Figure 4.4-1 (con't) Elements Q through S of the Sample Worksheet

5. TEST RESULTS

This chapter presents the results of several scenarios examined using the CSP. The main purpose of these runs is to examine the steady state behavior of the filter in different configurations. The section focuses on the data collected at the OMSTA Norway. The RDAS timing data used in this effort was provided to SYNETICS by USNO personnel; specific data intervals provided were:

- OMSTA Norway: 11 March 1989 (47596) through 12 April 1989 (47628)
- OMSTA Hawaii: 8 March 1989 (47593) through 12 April 1989 (47628)

The results presented in Section 5.1 were developed using a subset of this data. Additional plots for both the Norway and Hawaii Omega Stations are provided in a separate addendum (Reference 2).

Before presenting the data plots, a brief review of the thought process underlying this study will be useful. As mentioned in Chapter 3, the data collected by USNO is independent of the current Omega synchronization process. Specifically, the cesium timing is measured before any OMSFOG corrections. This allows us to use the collected data, without having to "back out" corrections, to hypothesize a new control scheme. An important part of the current study is to investigate how frequently corrections should be made in any new control scheme.

To proceed with this investigation, we will simulate obtaining data twice a day and estimating/correcting at the following rates: once a day, once every third day, once every fifth day, and once every seventh day. A comparison of the resulting performances will give an indication of benefits (which must be considered within the context of the entire Omega system error budget) to be derived from more frequent corrections.

For any given configuration, a correction or measurement update interval is selected. Although we say data is "collected" twice a day, we simulate an implementation scheme in which it is only provided as an input to the estimation filter at prescribed intervals (daily, every third day, etc.) The output of each measurement update filter cycle (performed at the prescribed interval) is an estimate of the phase and frequency offsets of the cesiums and the corresponding filter-indicated RMS errors, all valid at the measurement update time. To obtain estimates at times in between measurement incorporation events, the phase offset estimates are extrapolated forward

to the desired time using the frequency offset estimate. When the end of the prescribed measurement update interval is reached, this extrapolated estimate is corrected with the new measurement data.

The degree to which the extrapolated phase offset estimate accurately reflects the true phase offset will clearly decrease as the measurement update interval is extended. A measure of this deviation is provided by the phase offset residual plots. These plots show the difference between the predicted phase offsets at the time at which a set of corrections is requested, and the actual measurement data which is "revealed to the filter" an "update interval" later. An assessment of these residuals, for various update intervals, is what constitutes the major output of this study.

5.1 TEST CONFIGURATIONS

Five distinct measurement sets are examined with each set defining a configuration. Within each configuration, the update rates were varied with a maximum update interval of 7 days. The selected configurations are illustrated pictorially in Figure 5.1-1. For each configuration, Figure 5.1-1 shows the four main units: the online cesium, the secondary cesium, the primary cesium, and the GPS Datum Monitor, with directed arrows joining them. The arrows designate which measurements are defined in the configuration. Configuration I is discussed in some detail with the intent of explaining the significance of the various plot types provided by the CSP. The measurement sets available at the OMSTAs Hawaii and Norway are provided in Table 5.1-1.

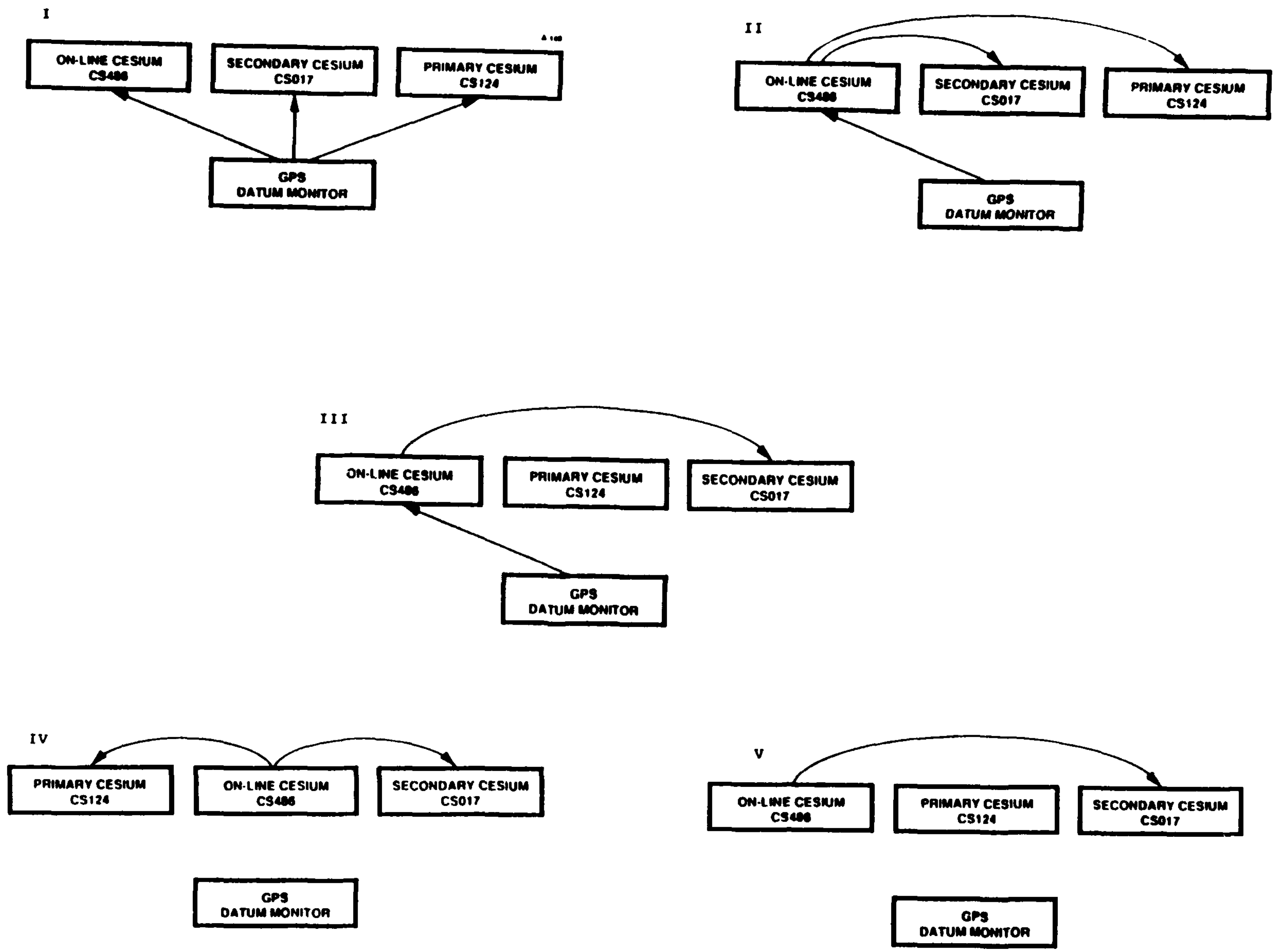


Figure 5.1-1 Test Configurations

TABLE 5.1-1
RDAS TIMING DATA MEASUREMENTS

PHASE OFFSET MEASUREMENT	OMEGA STATION	MEASUREMENT DESIGNATION
Time difference between GPS and online cesium	Norway	GPS-CS486=(GPS-CS124)-(CS486-CS124)
	Hawaii	GPS-CS529=(GPS-CS554)-(CS529-CS554)
Time difference between GPS and secondary cesium	Norway	GPS-CS017
	Hawaii	GPS-CS349
Time difference between GPS and primary cesium	Norway	GPS-CS124
	Hawaii	GPS-CS554
Time difference between online and secondary cesiums	Norway	CS486-CS017
	Hawaii	CS529-CS349
Time difference between online and primary cesiums	Norway	CS486-CS124
	Hawaii	CS529-CS554

5.1.1 **Configuration I (Norway)**

In configuration I the available measurement set was assumed to consist of GPS/cesium measurements for each of the three cesiums: online, primary, and secondary. With this measurement set, the six-state filter reduces to a set of three uncoupled two state filters. In this uncoupled configuration the estimate of the online clock phase offset and frequency depend only on the GPS/ online cesium measurements. This same relation between the measurements and the state estimates also exists for the primary and secondary clocks.

Several different runs were performed in this configuration, with the interval between measurement updates, that is the interval at which measurements are provided to the filter, varied between 0.5 days and 7 days. In the following two subsections the 0.5 day and 5 day interval cases are examined. Since the run with the 0.5 day update interval is, within the context of the cases examined, a best case, this run will serve as a baseline with which to compare the results of other runs in this configuration as well as runs in other configurations.

5.1.1.1 *Configuration I - 0.5 day update interval*

The filter's phase and frequency estimates for each of the three cesiums are provided in Figures 5.1-2 and 5.1-3, respectively. Note that for plotting purposes, the initial phase offset estimate used by the filter is subtracted out of the data record ensuring each of the records begin at zero. The online clock (CS486) phase offset estimate is seen to remain very stable throughout the interval. This is consistent with the frequency offset estimate for CS486 which remains near zero. Both CS124 and CS017 show more evident phase offset drifts. The frequency offset estimates for these two cesiums are somewhat less stable than those of CS486.

The phase offset residuals, given in Figure 5.1-4, provide a measure of the performance of the filter. For this minimum update rate case, these residuals reduce to the difference between the actual measurement and the measurement updated estimate. Throughout the interval these residuals remain below the 0.1 microsecond (100 nanosecond) level. The largest residuals are those of CS124 which occur near day 20. As is evident, a high degree of correlation exists between the three phase offset residuals. The noise in each of the three GPS/cesium phase measurements is mainly the result noise in the GPS outputs, and is thus common to each of the three measurements.

The filter-indicated RMS errors for each of the three phase offset states are provided in Figure 5.1-5. These values indicate the filter's estimate of the uncertainty in the provided estimates. Although the true errors are not available for comparison, the relative consistency of the phase offset residuals with the filter indicated RMS values is an indication of reasonable performance. A large discrepancy between these two quantities, specifically a diverging residual and stable filter RMS value, may be taken as an indication of mismodeling. No problem of this type is evident here.

5.1.1.2 *Configuration I - 5 day update interval*

In this run the same configuration as above was used but the interval between measurement updates was lengthened from 0.5 days to 5 days. Plots summarizing this run are provided in Figures 5.1-6 through 5.1-9. The updated phase estimates from day one of an update interval are propagated forward using the updated frequency estimates until the next measurement becomes available to the filter. When this next measurement is received, the filter's measurement update step is executed and the propagated estimate is updated. This propagation and update cycle is evident in the state estimates (Figure 5.1-6) and the filter RMS error estimate (Figure 5.1-9). The measurement update events are evident in these plots occurring at days 5, 10, etc.

The phase offset estimates show the same general behavior as was observed in the 0.5 day update interval case. The frequency offset estimates are also similar to those of the 0.5 day update interval case. Since no frequency rate terms are maintained by the filter, the frequency offset estimates are held constant between measurement updates and change only at these events.

The phase offset residuals (Figure 5.1-8) again provide a measure of the error in the phase offset estimates. The residuals for all three clocks remain below 0.25 microseconds (250 nanoseconds) throughout the interval. The largest residuals are those associated with CS124 and occur near day 24 and day 29, both days corresponding to ends of a filter update cycle with measurement updates occurring on days 25 and 30. Some portion of this error may be attributed to an apparent error in the frequency offset estimates for CS124 near these days. An error in the frequency offset estimate on the order of 0.03 microseconds/day, for example, will propagate into a phase offset estimate error of magnitude 0.15 microseconds at the end of a five day period. Some measure of the error in the frequency offset estimate in this case may be gained by comparing with

the corresponding frequency offset for the 0.5 day update interval case. At the measurement update times (days 5, 10, 15, etc.) the phase offset residuals for each of the clocks drops to near zero. The filter has effectively "reset" its phase offset estimate to the value of the newly received phase offset measurement. This behavior is consistent with the relative smallness of the assumed uncertainty in the GPS/cesium measurements as compared to the uncertainty in the a priori estimate, as expressed in the propagated error covariance.

Much of the noise evident in the each of the three residuals is a result of noise in the GPS/cesium measurements, rather than in the estimates themselves. This may be inferred since the estimates change smoothly (linearly) between updates, and may also be verified by examining the raw data. As in the 0.5 day case, a high degree correlation exists between the three residuals.

The filter indicated RMS errors (Figure 5.1-9) range between 0.05 microseconds, just after a measurement update and 0.13 microseconds just before an update. The growth between estimates is due to the inclusion of the process noise matrix. Note that the post-update RMS error (0.05 microseconds) matches the value assumed for the GPS/cesium measurements (σ_{GC} = 0.05 μsec).

5.1.2 **Configuration II** (Norway)

As in configuration I, the measurement set assumed here is sufficient to obtain reasonable estimates of the phase offsets for each of the cesiums. In this case, however, only one direct GPS/cesium measurement is used. To complete the measurement set, online/primary and online/secondary measurements are included. The 0.5 day update interval case is summarized in Figures 5.1-10 through 5.1-13 and the 5 day update interval case is summarized in Figures 5.1-14 through 5.1-17. The basic behavior of the phase and frequency offset plots is the same as was observed for Configuration I. Some slight differences in the residual plots for the two configurations can be seen. The phase offset residuals for Configuration II tend to be slightly larger when compared to the same update interval case in Configuration I. Larger phase offset residuals for the primary and secondary cesiums might be expected, since only indirect measurement of the phase offsets of these clocks are used in this configuration.

5.2 *DISCUSSION*

In this chapter CSP results for configurations I and II have been presented using Norway data. These two configurations represent nominal cases in that a sufficient measurement set is available to estimate the states of each of the three clocks. For each of the two configurations, two different measurement update schedules, 0.5 days and 5 days, were examined. These runs served to confirm the integrity of the basic filter design. In all cases reasonable estimates were maintained and no instances of divergent behavior were noted. No significant difference between the two main configurations were observed, although the phase offset residuals for the configuration I runs were slightly smaller in magnitude. The largest phase offset residual recorded during the runs presented in this chapter was on the order of 300 nanoseconds.

The addendum that accompanies this report (Reference 2) examines additional measurement configurations and measurement update intervals, using both Hawaii and Norway data. In reviewing these plots, the reader should focus his attention on the phase offset residual plots. To help in a review of this data, a record of the maximum residual recorded for each of the three configurations involving GPS/cesium measurement (configurations I, II, and III) was recorded. This information was obtained by reviewing the phase offset residual plots for each run and selecting the absolute maximum value and is provided in Table 5.2-1 for OMSTA Norway and Table 5.2-2 for OMSTA Hawaii. In configuration III the measurement set is such that the phase offset estimate cannot be computed for one of the cesiums (i.e., CS124 at Norway, and CS554 at Hawaii); the corresponding columns in the tables are thus left blank. Note the variations between the different configurations and different update intervals is relatively small. This is primarily due to the fact that the frequency offset estimates of the cesiums remain relatively constant over the interval.

The same approach was taken with the Hawaii data as was used with the Norway with one exception. Due to GPS coverage limitations at the Hawaii station, GPS measurement data was not always available at each half day interval as was the case at Norway. The topography at OMSTA Hawaii is such that satellites at low elevations are obscured for a large range of azimuths. This fact, combined with the fact that only a limited constellation was in place, resulted in the periodic loss of GPS measurement data. To overcome this limitation in the CSP runs, the basic minimum interval at which measurements were used for residual computations in the CSP was increased to 1 day for the Hawaii scenarios. This spacing was found to be sufficient to avoid the measurement

outages. In the Norway scenarios examined in this report, and provided in the addendum, the basic interval of 1/2 day was used. To help the reader interpret the Hawaii plots provided in the addendum, a sample Hawaii phase offset residual plot is provided in Figure 5.2-1 corresponding to the five day measurement update interval scenario. This plot shows the residual computed at 1 day intervals, rather than 1/2 day intervals.

The initial phase offset estimates for the cases examined above, as well as for those examined in the addendum, were set at the initial GPS/cesium measurements. This selection was made since our main interest is in the steady state response of the filter. This aspect of performance is the most relevant for any hypothesized synchronization scheme that uses GPS data. Although of less interest for the objectives of this report, the transient response of the filter was also examined for additional verification of filter performance. This was accomplished by injecting an arbitrary error in the initial phase offset estimate and verifying that the estimates eventually converged to reasonable values. A sample case that illustrates this transient behavior is provided in Figures 5.2-2 and 5.2-3, showing the phase offset estimates and phase residuals, respectively. The initial errors injected for this test case ranged between 0.3 and 1.2 microseconds. Although a longer time period is required for the filter to reach the point were it is maintaining stable estimates, this point is eventually reached.

TABLE 5.2-1
NORWAY OMEGA STATION RESIDUALS

ABSOLUTE MAXIMUM PHASE OFFSET RESIDUALS (microseconds)			
Configuration I	**CS486**	**CS017**	**CS124**
1.0 day update	.031	.111	.080
3.0 day update	.182	.289	.180
5.0 day update	.173	.177	.233
7.0 day update	.191	.278	.229
Configuration II	**CS486**	**CS017**	**CS124**
1.0 day update	.034	.198	.156
3.0 day update	.166	.299	.154
5.0 day update	.159	.269	.275
7.0 day update	.174	.270	.206
Configuration III	**CS486**	**CS017**	**CS124**
1.0 day update	.040	.201	
3.0 day update	.173	.297	
5.0 day update	.153	.262	
7.0 day update	.176	.269	

TABLE 5.2-2
HAWAII OMEGA STATION RESIDUALS

ABSOLUTE MAXIMUM PHASE OFFSET RESIDUALS (microseconds)			
Configuration I	**CS529**	**CS349**	**CS554**
1.0 day update	.053	.084	.092
3.0 day update	.115	.159	.185
5.0 day update	.148	.189	.154
7.0 day update	.178	.189	.120
Configuration II	**CS529**	**CS349**	**CS554**
1.0 day update	.069	.109	.101
3.0 day update	.112	.158	.173
5.0 day update	.147	.189	.149
7.0 day update	.154	.189	.134
Configuration III	**CS529**	**CS349**	**CS554**
1.0 day update	.058	.099	
3.0 day update	.109	.152	
5.0 day update	.148	.189	
7.0 day update	.170	.189	

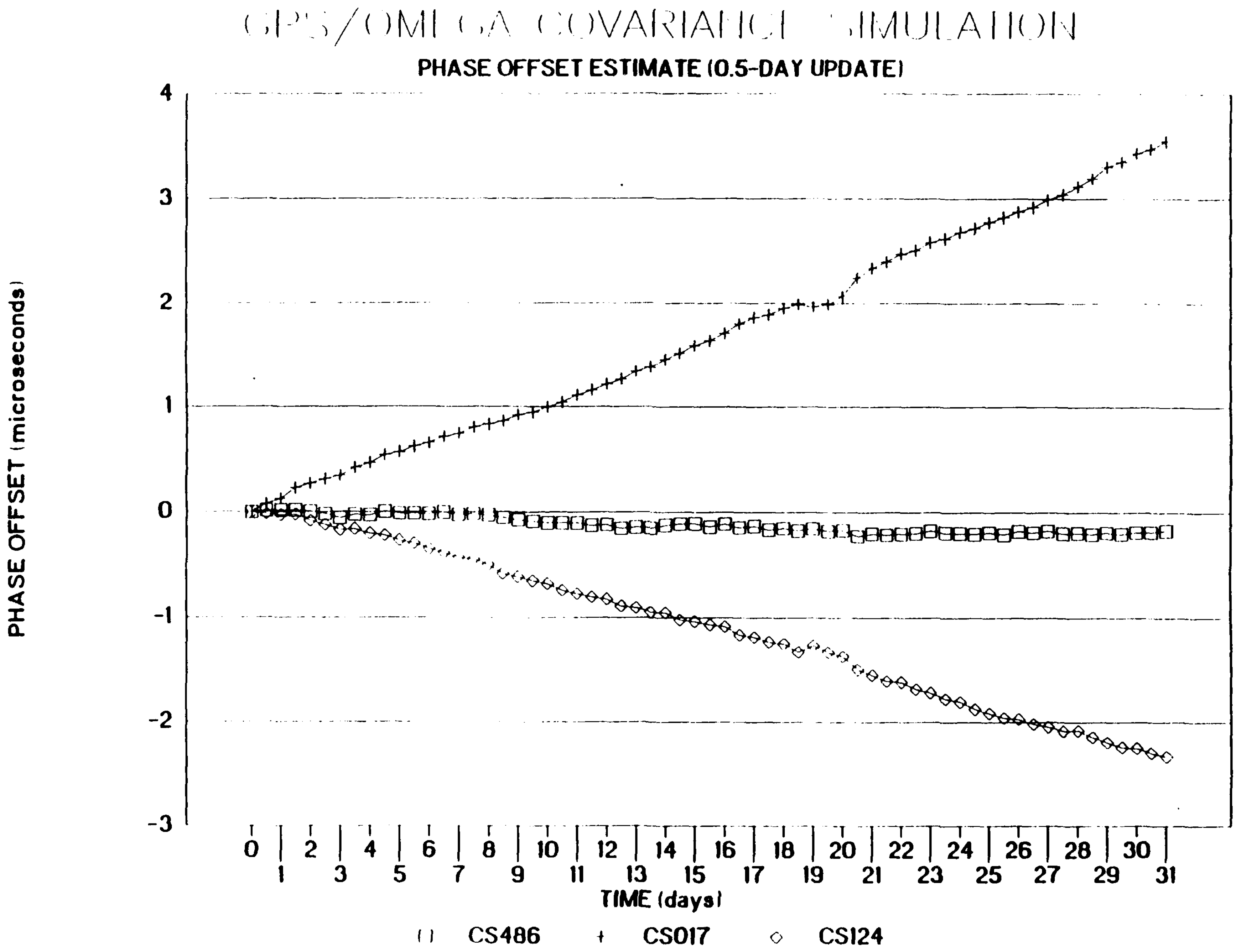


Figure 5.1-2 Configuration I - Phase Offset Estimates (0.5 day)

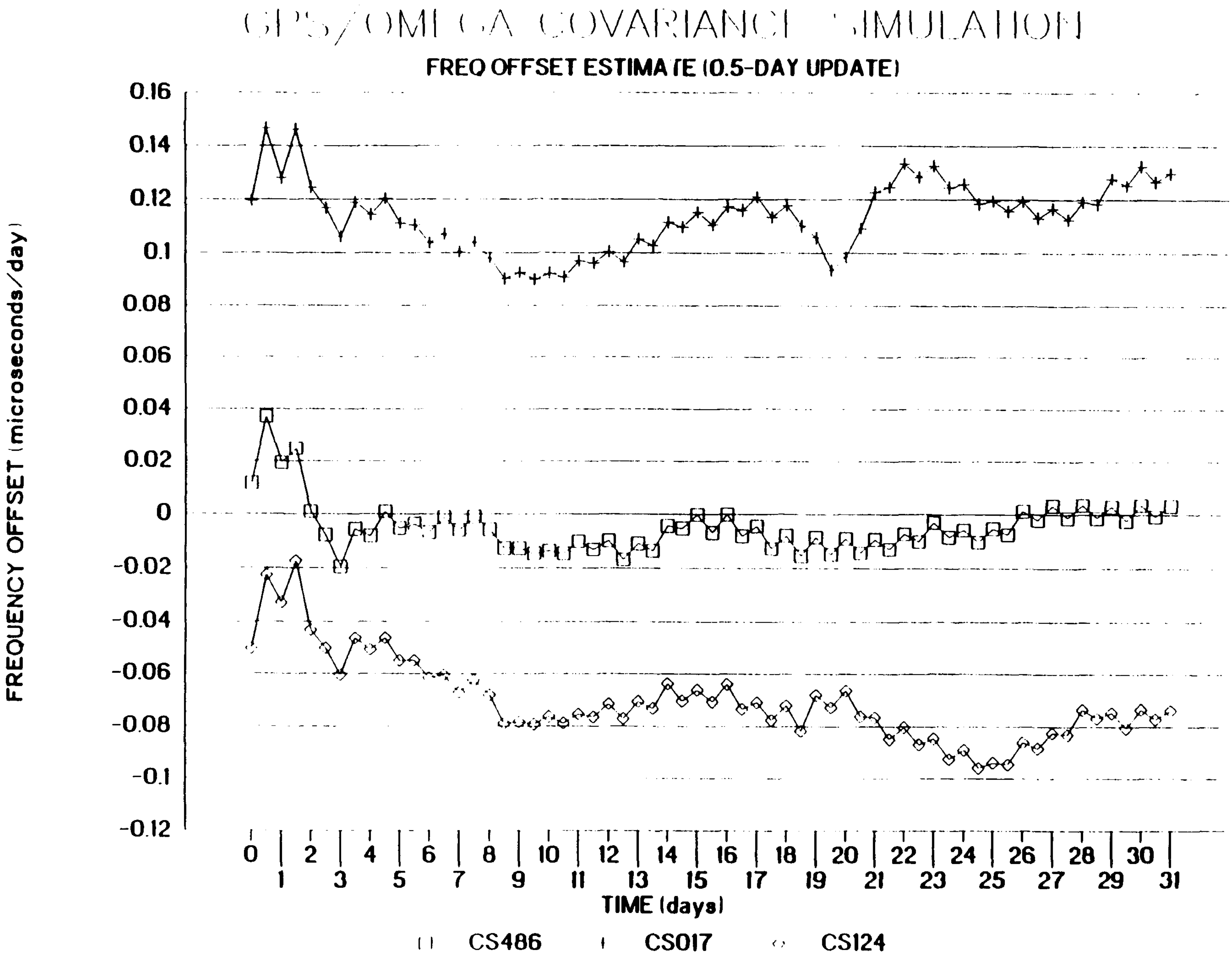


Figure 5.1-3 Configuration I - Frequency Offset Estimates (0.5 day)

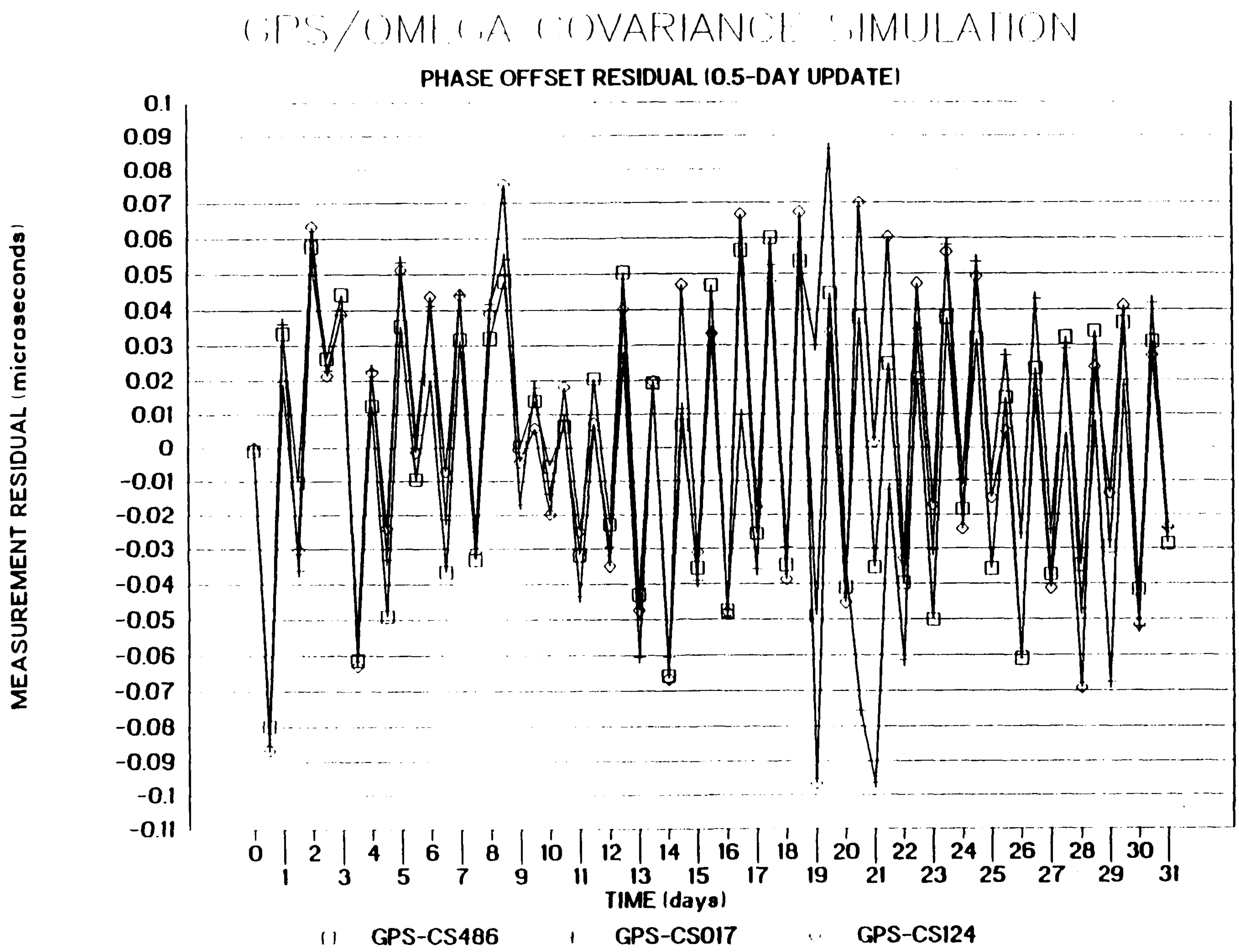


Figure 5.1-4 Configuration I - Phase Offset Residuals (0.5 day)

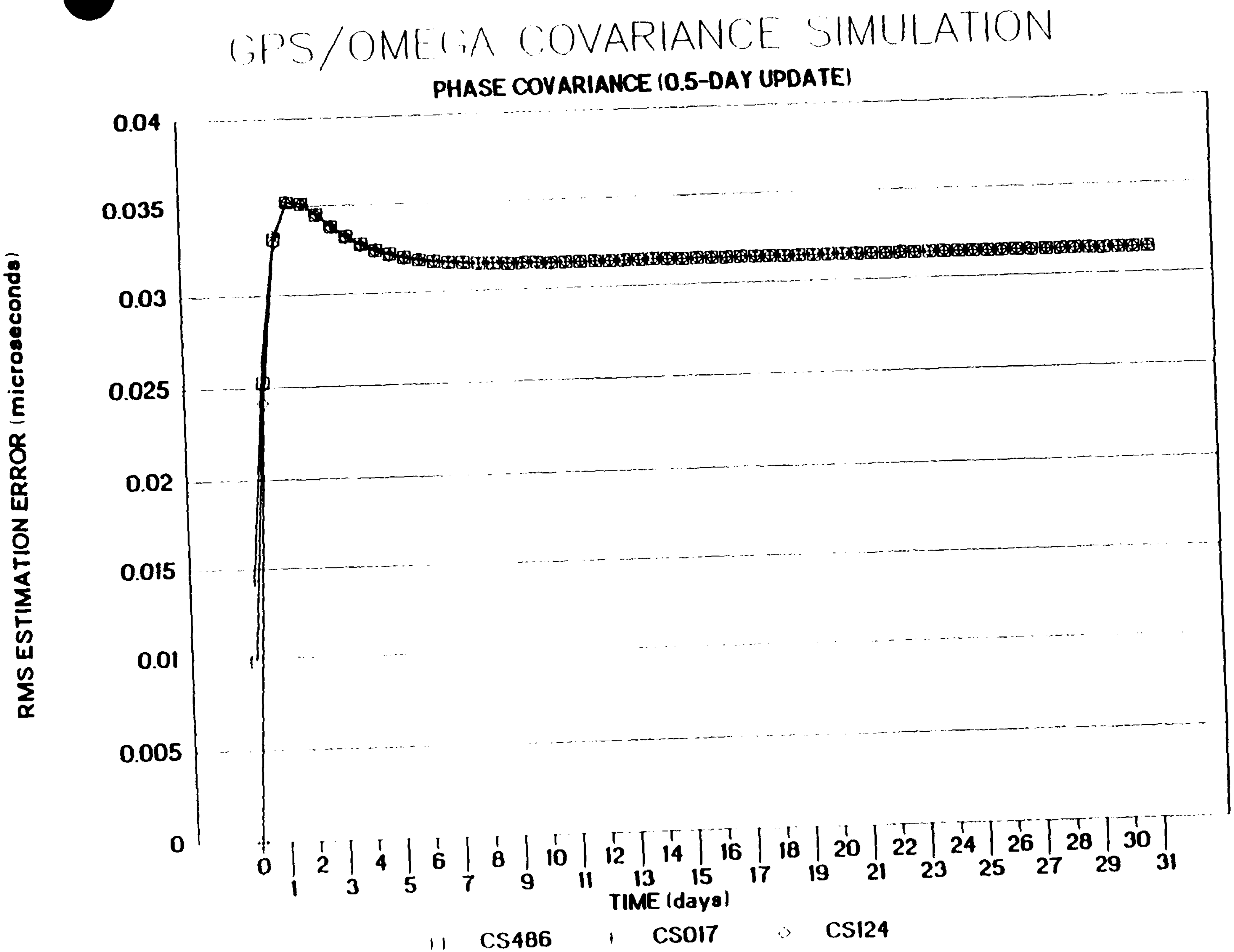


Figure 5.1-5 Configuration I - Filter Indicated RMS Phase Offset Errors (0.5 day)

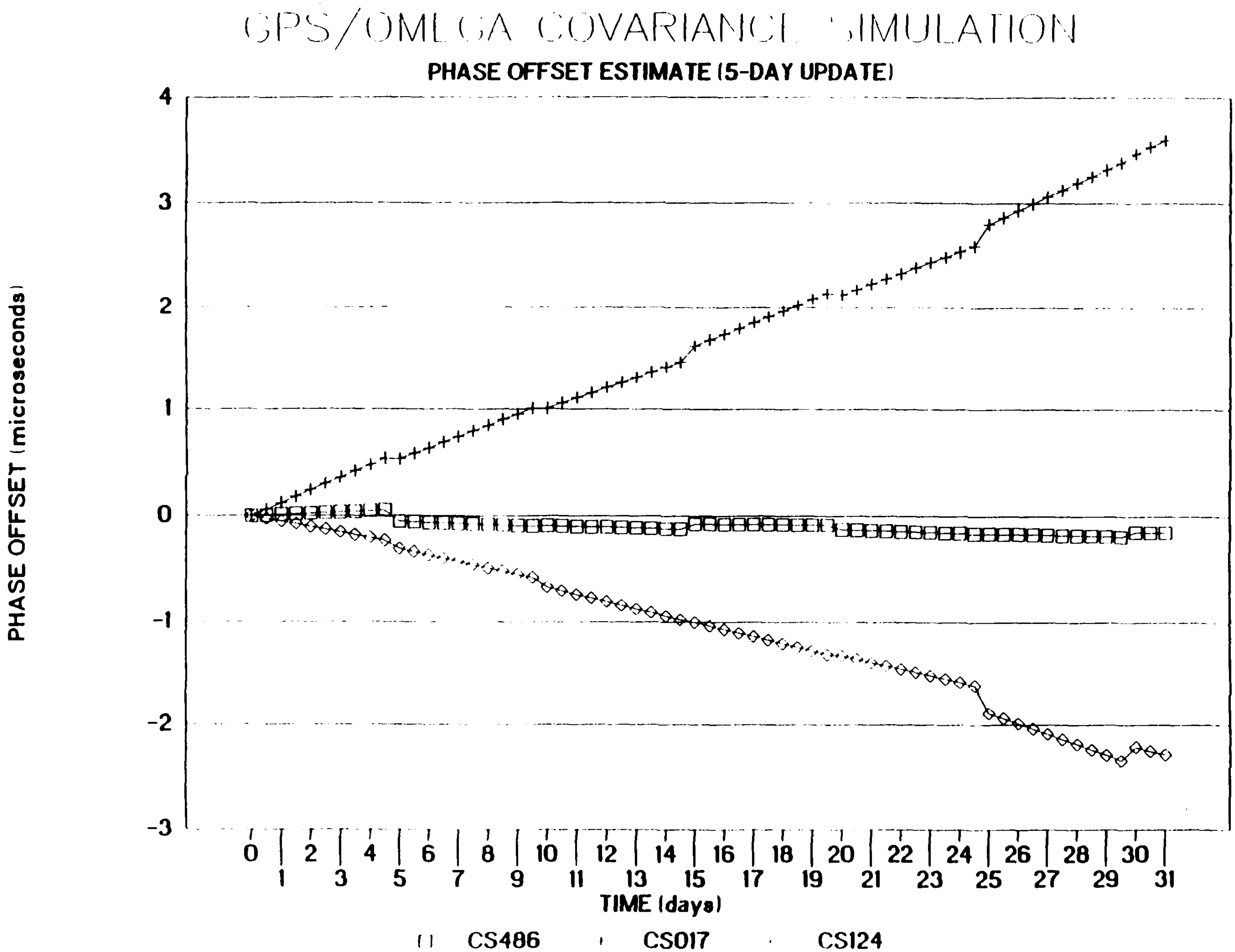


Figure 5.1-6 Configuration I - Phase Offset Estimates (5 day)

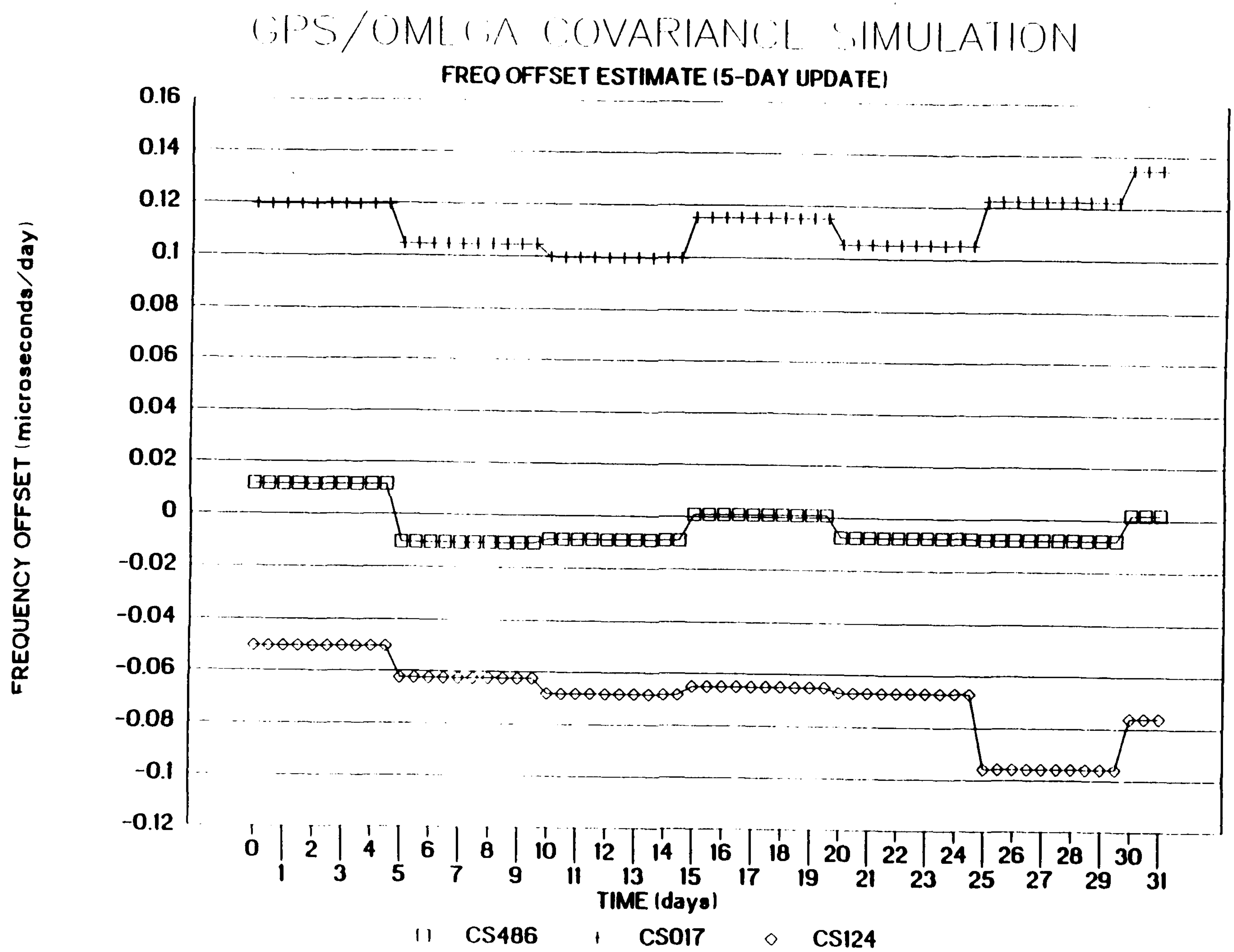


Figure 5.1-7 Configuration I - Frequency Offset Estimates (5 day)

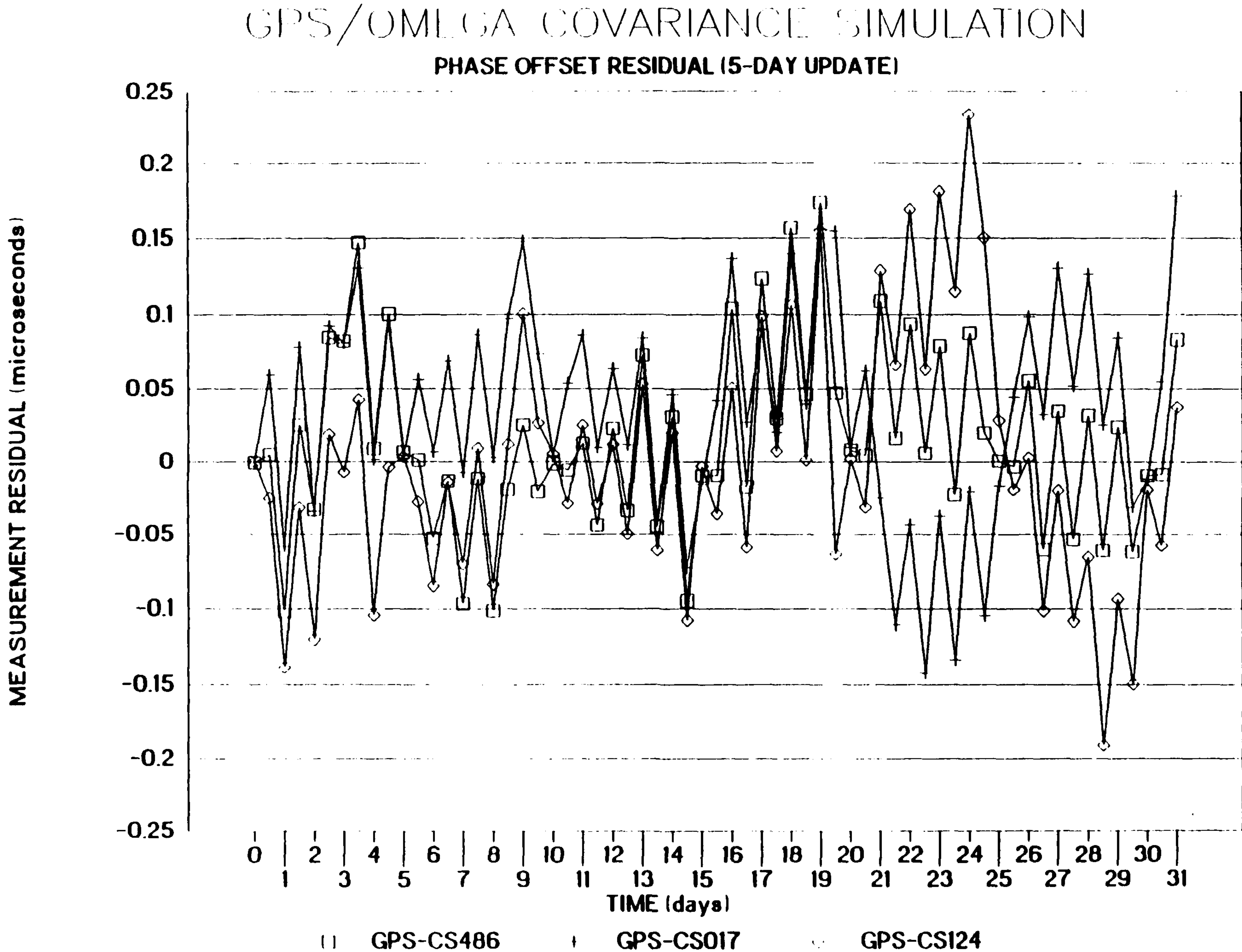


Figure 5.1-8 Configuration I - Phase Offset Residuals (5 day)

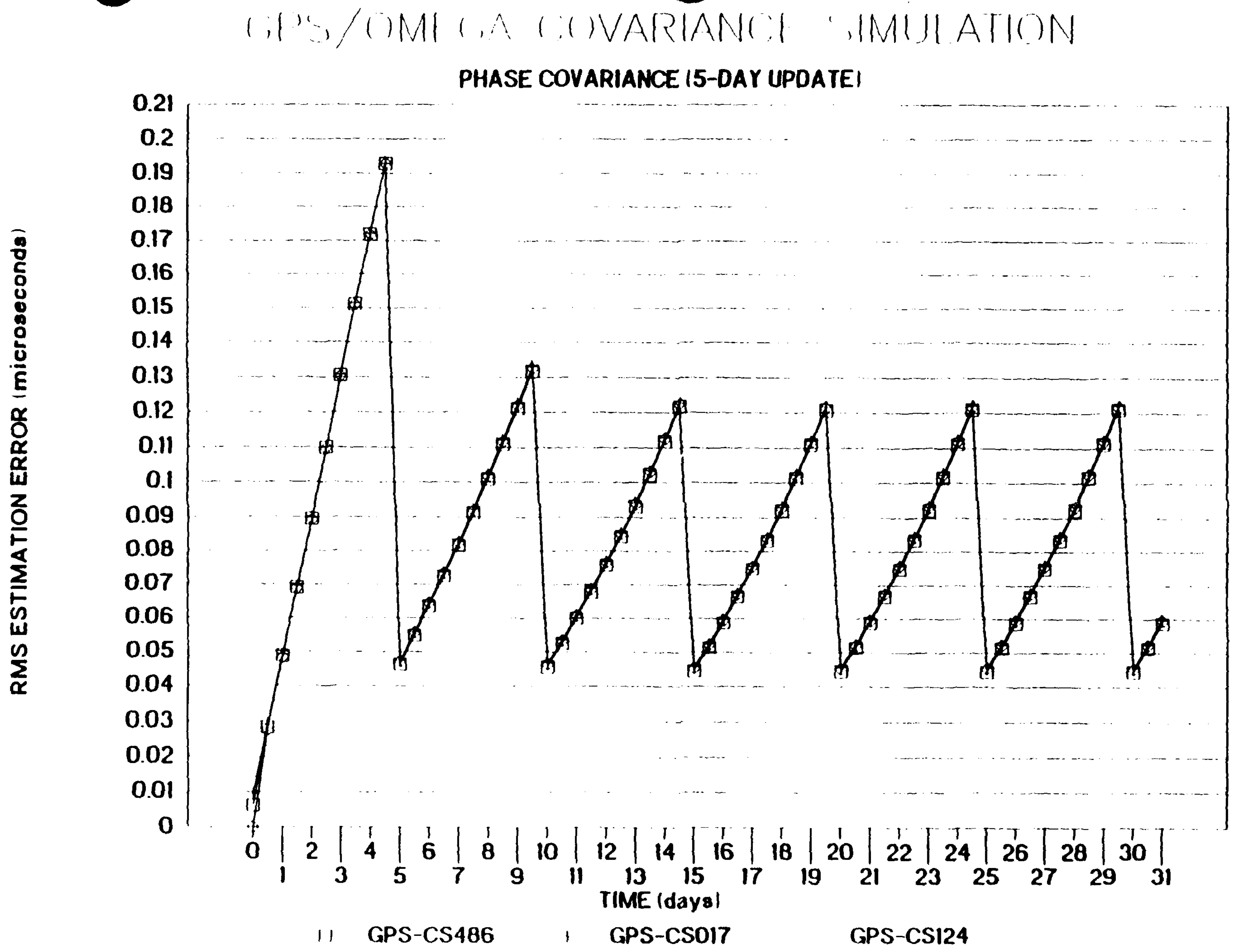


Figure 5.1-9 Configuration I - Filter Indicated RMS Phase Offset Errors (5 day)

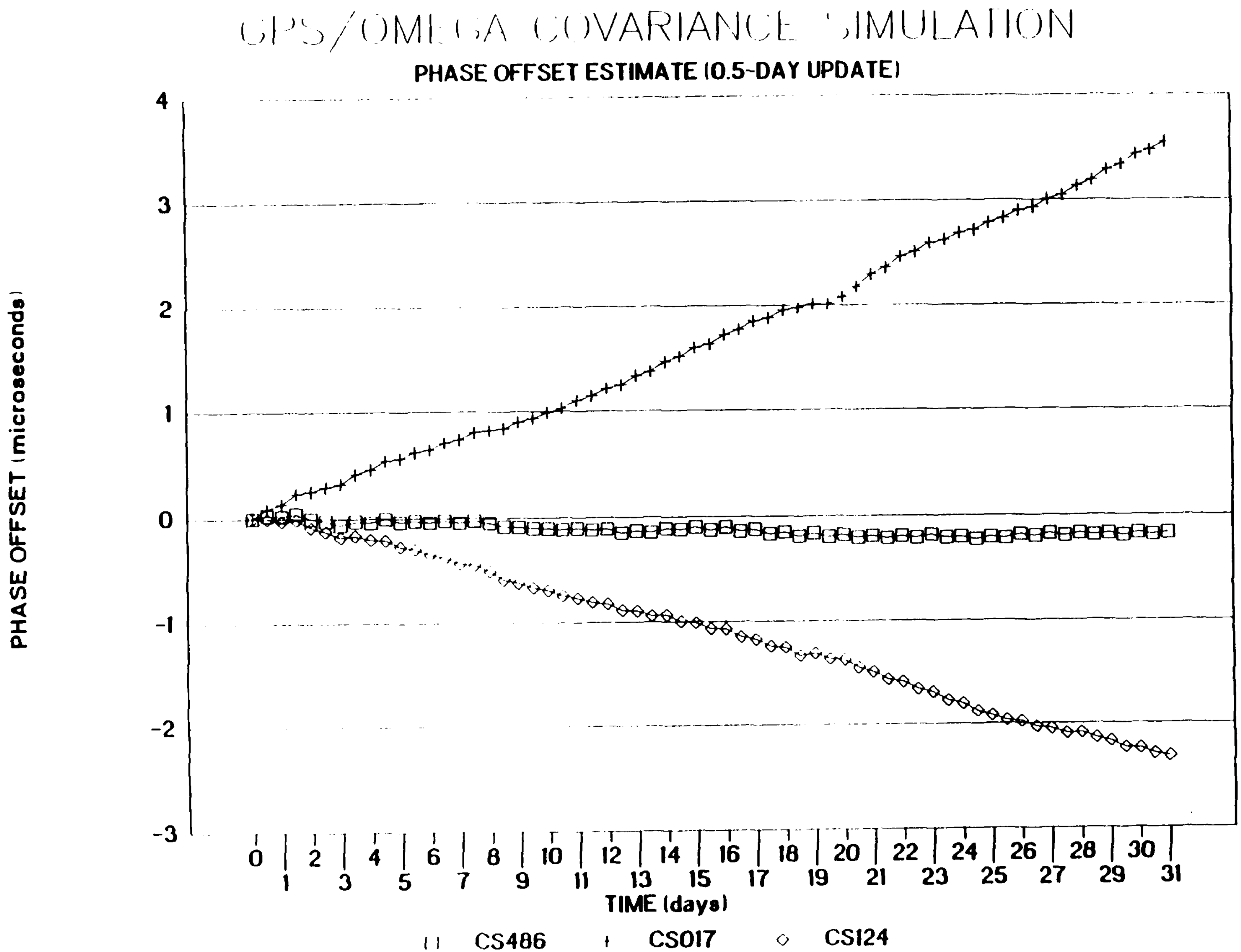


Figure 5.1-10 Configuration II - Phase Offset Estimates (0.5 day)

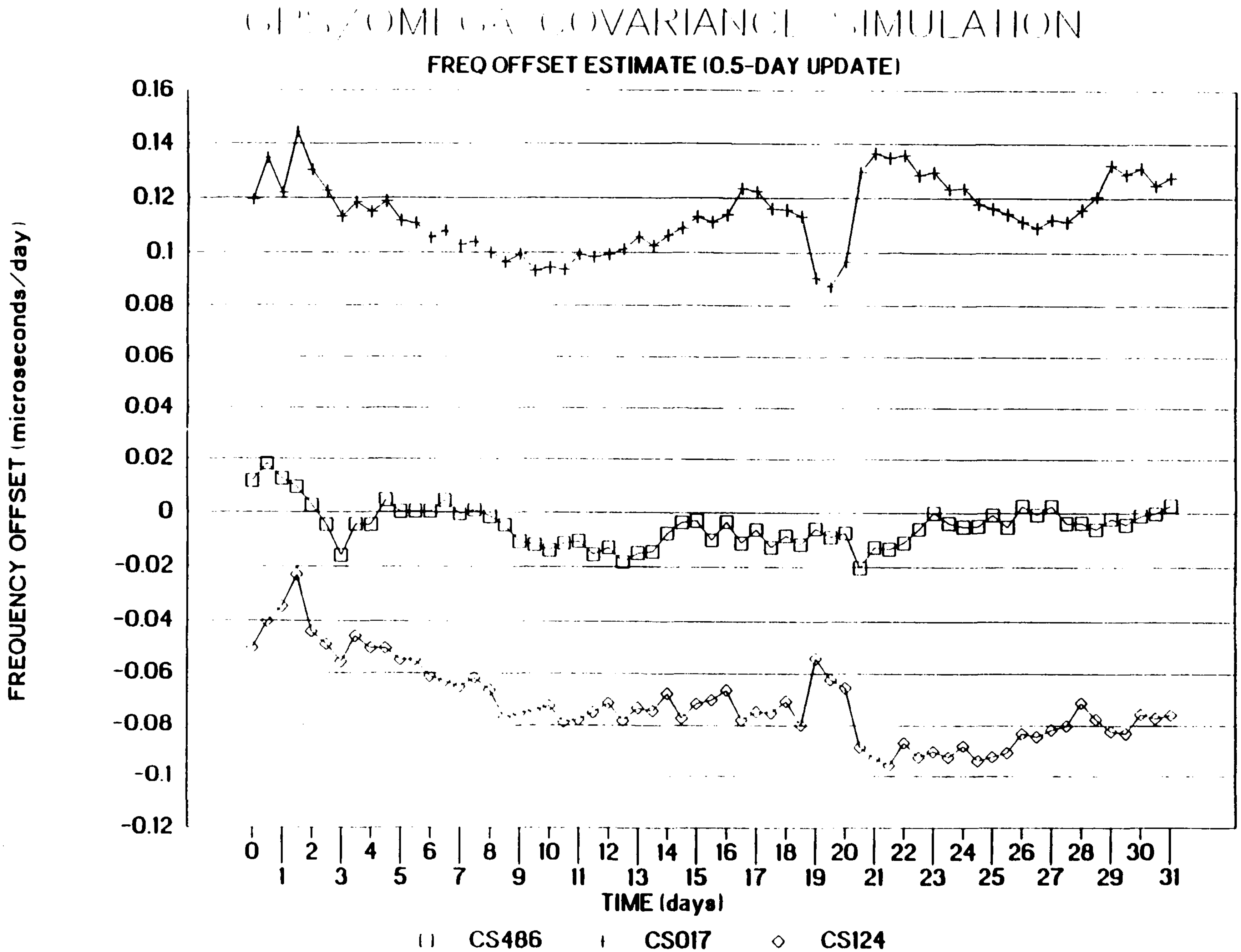


Figure 5.1-11 Configuration II - Frequency Offset Estimates (0.5 day)

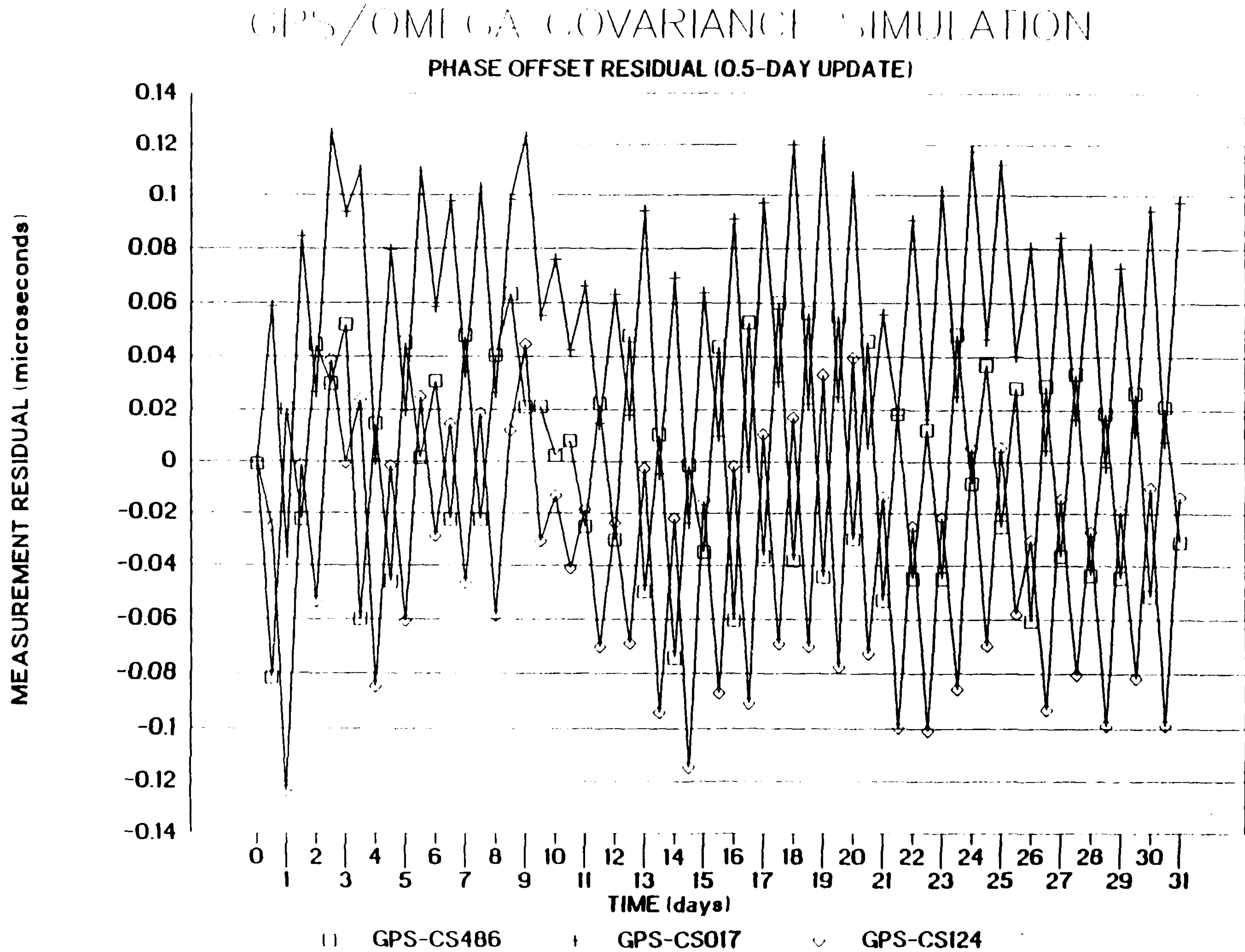


Figure 5.1-12 Configuration II - Phase Offset Residual (0.5 day)

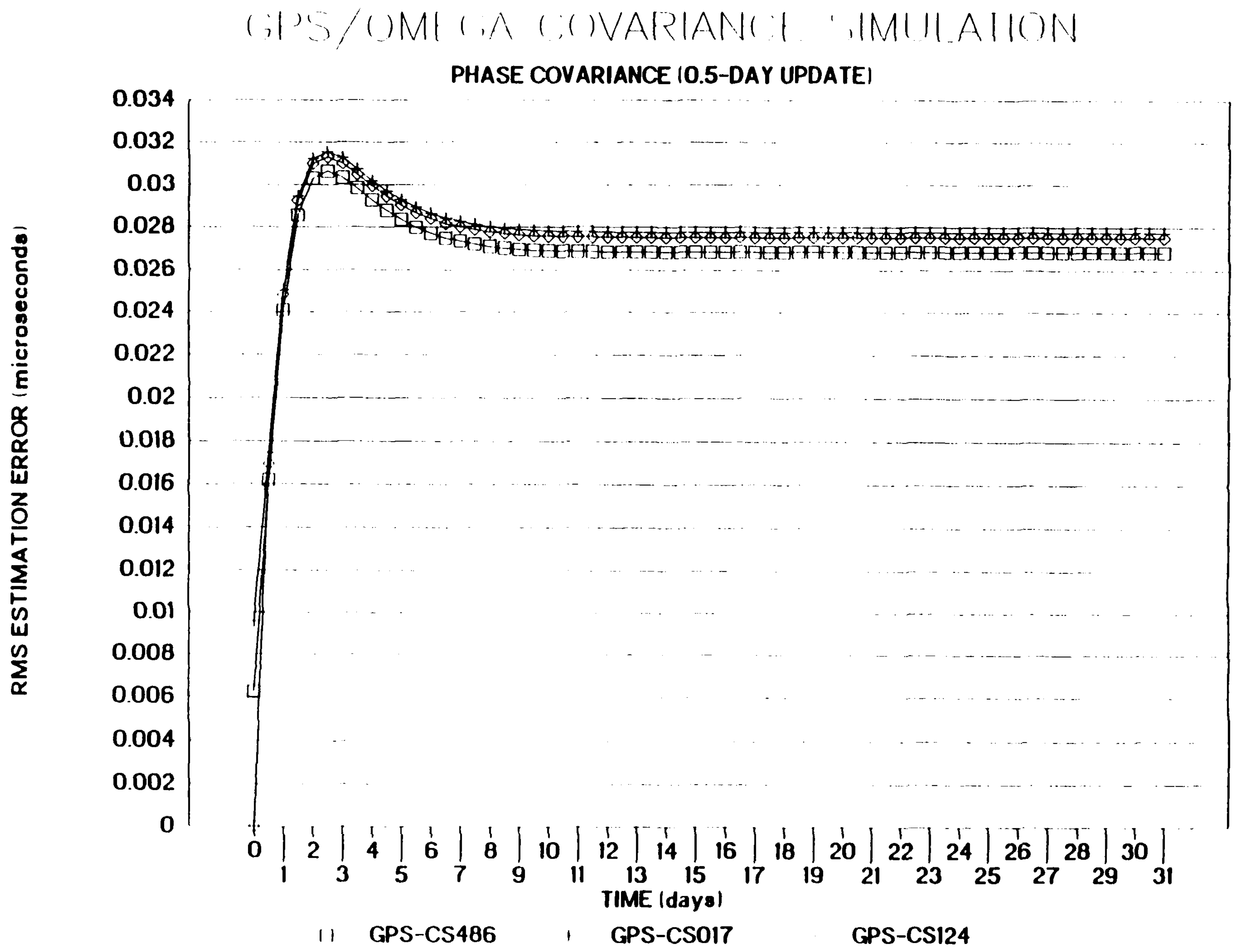
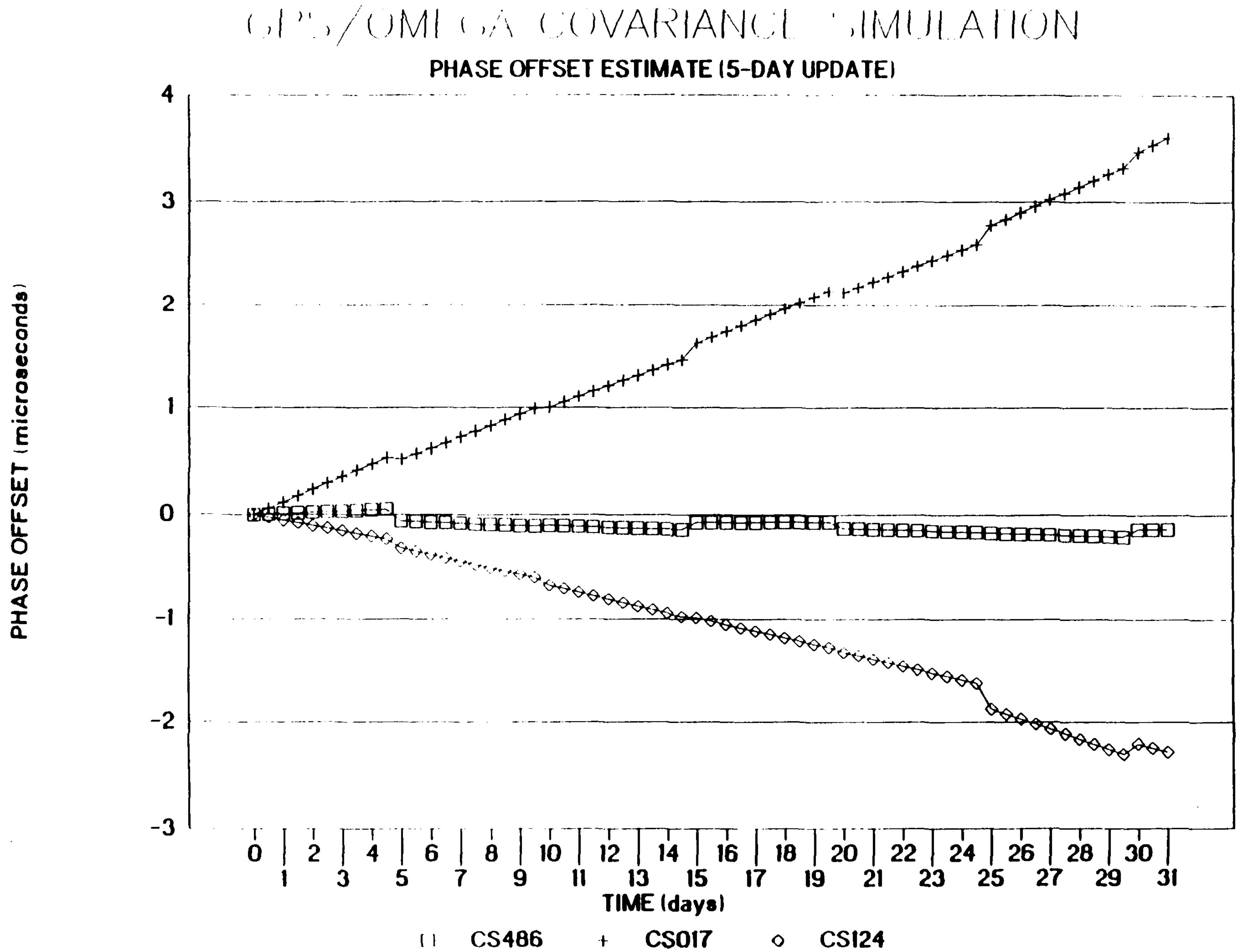
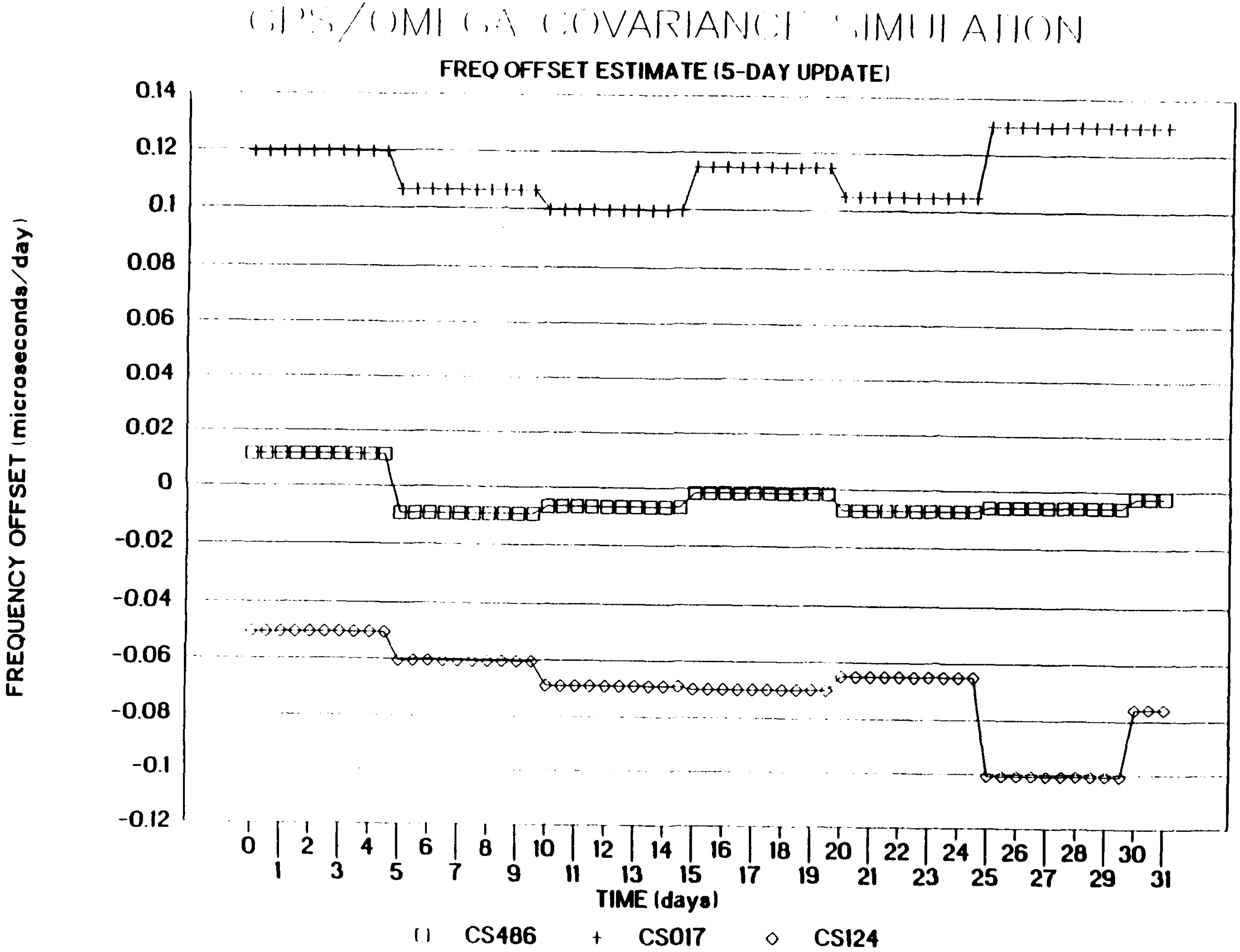


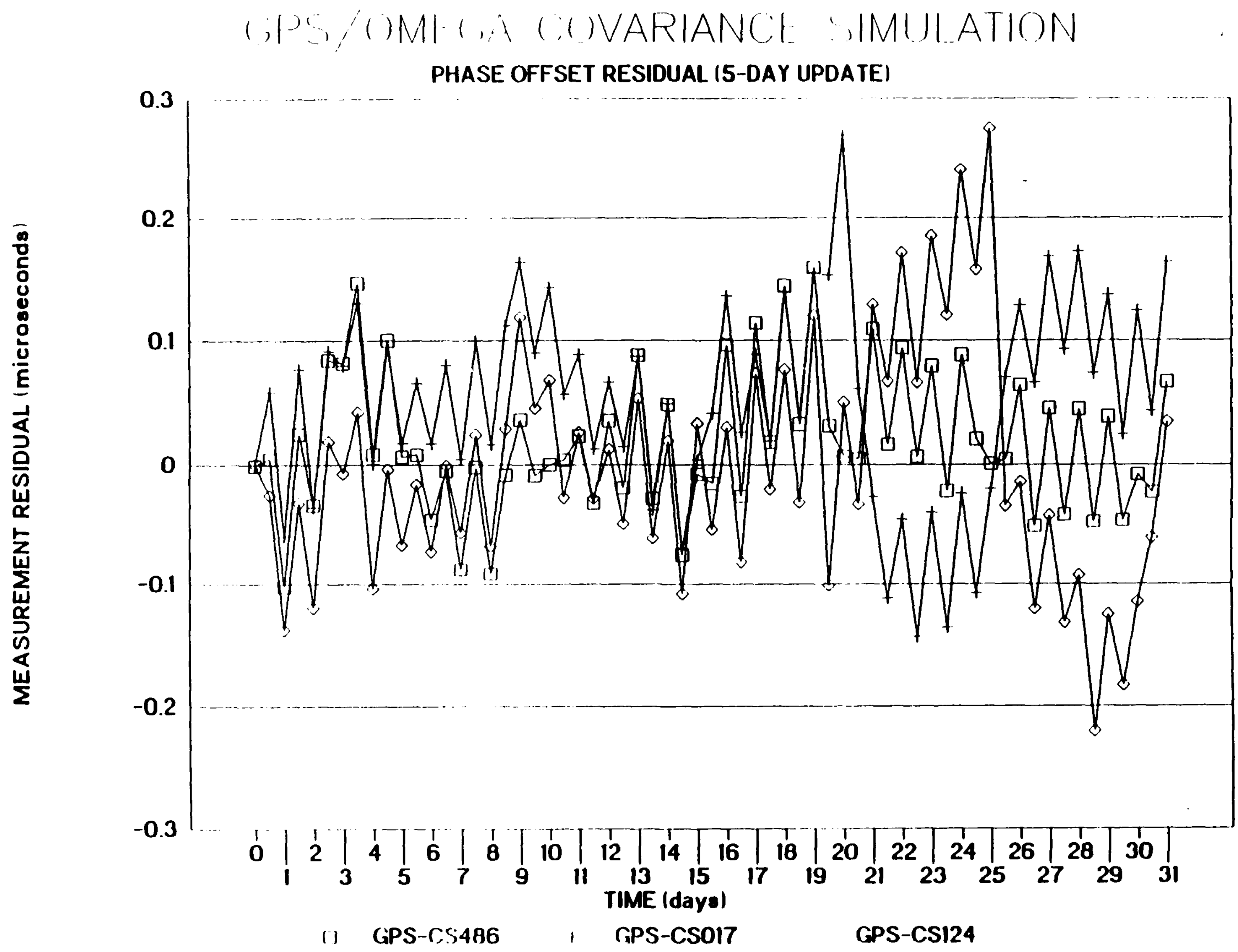
Figure 5.1-13 Configuration II - Filter Indicated RMS Phase Offset Errors (0.5 day)



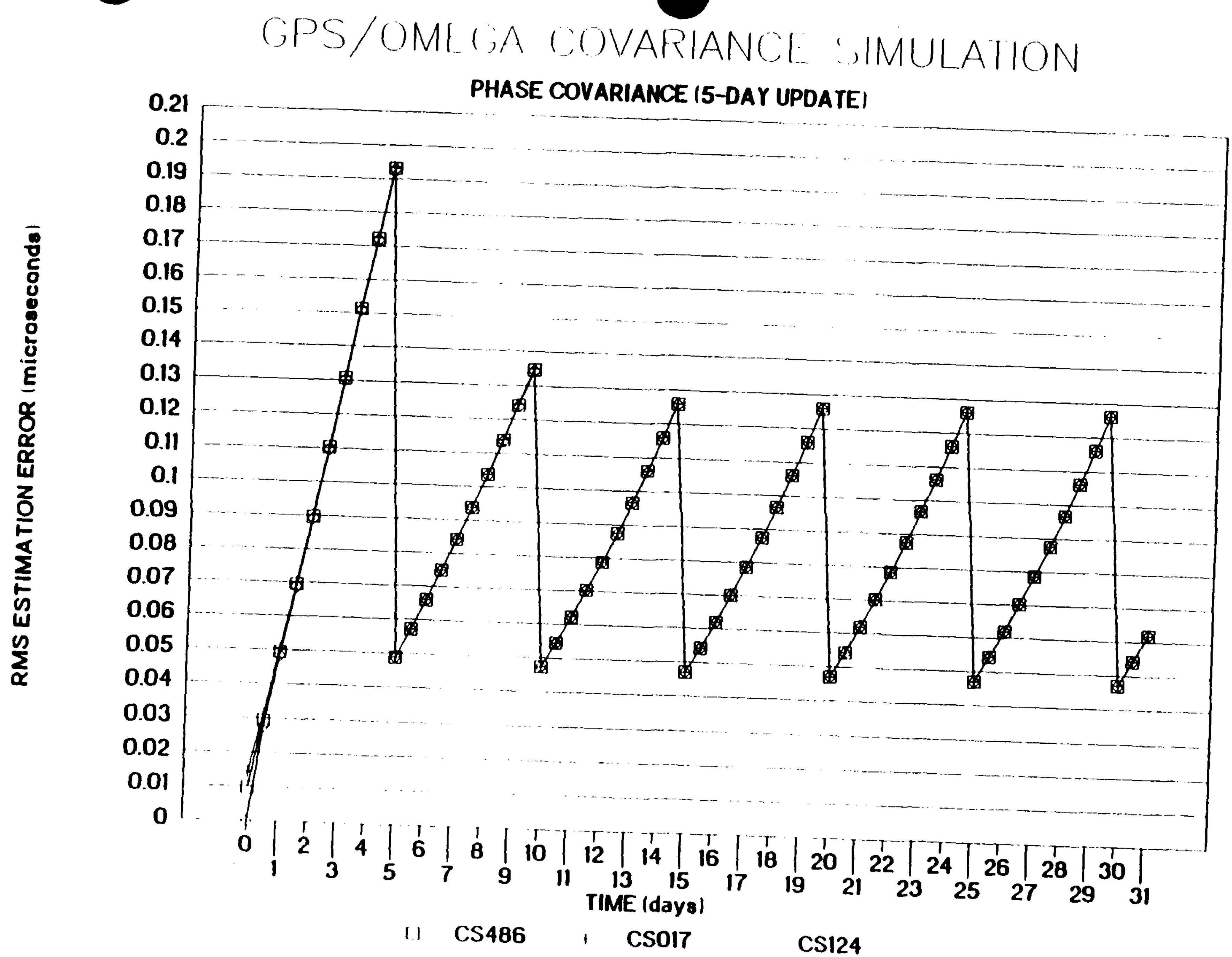
5.1-14 Configuration II - Phase Offset Estimates (5 day)



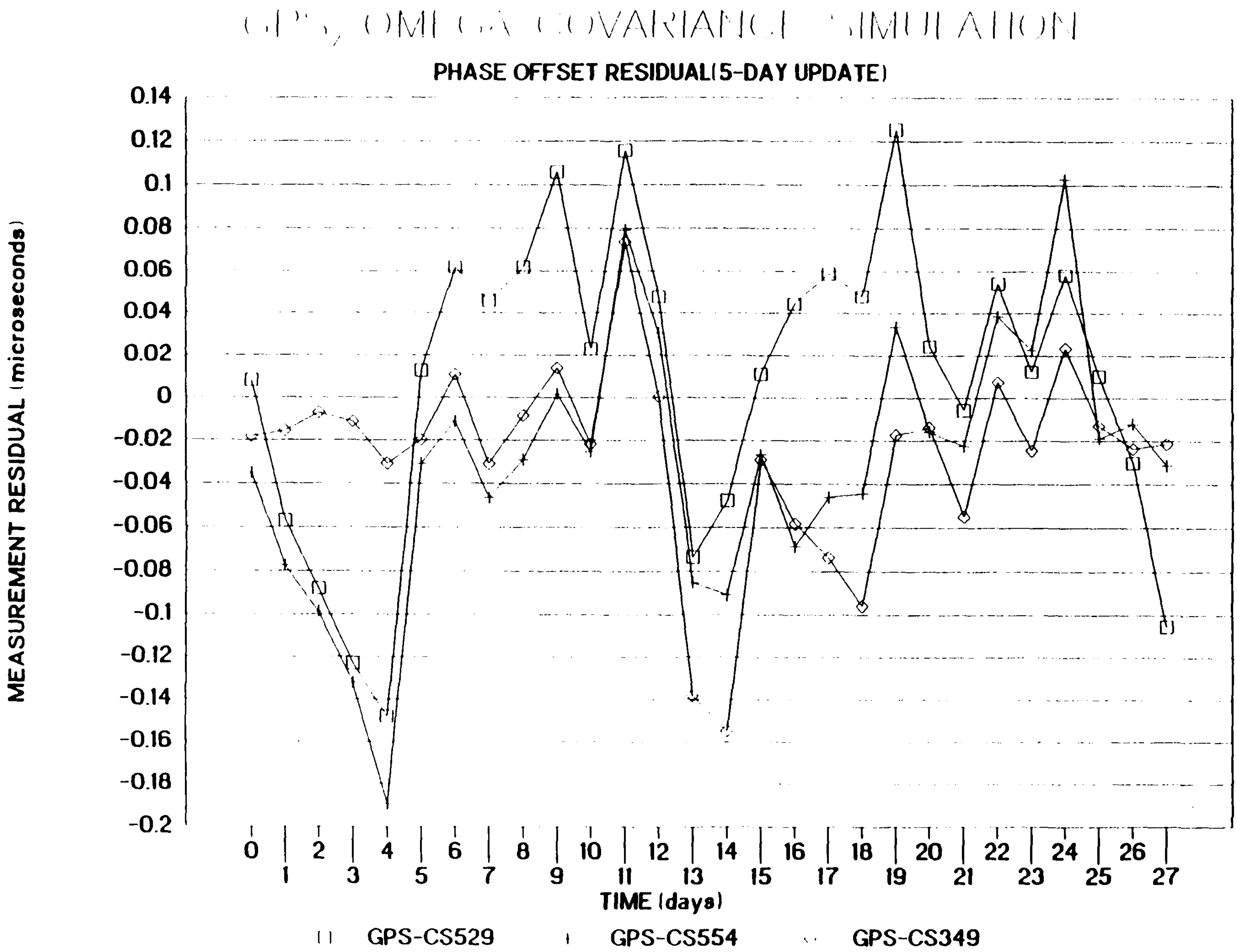
5.1-15 Configuration II - Frequency Offset Estimates (5 day)



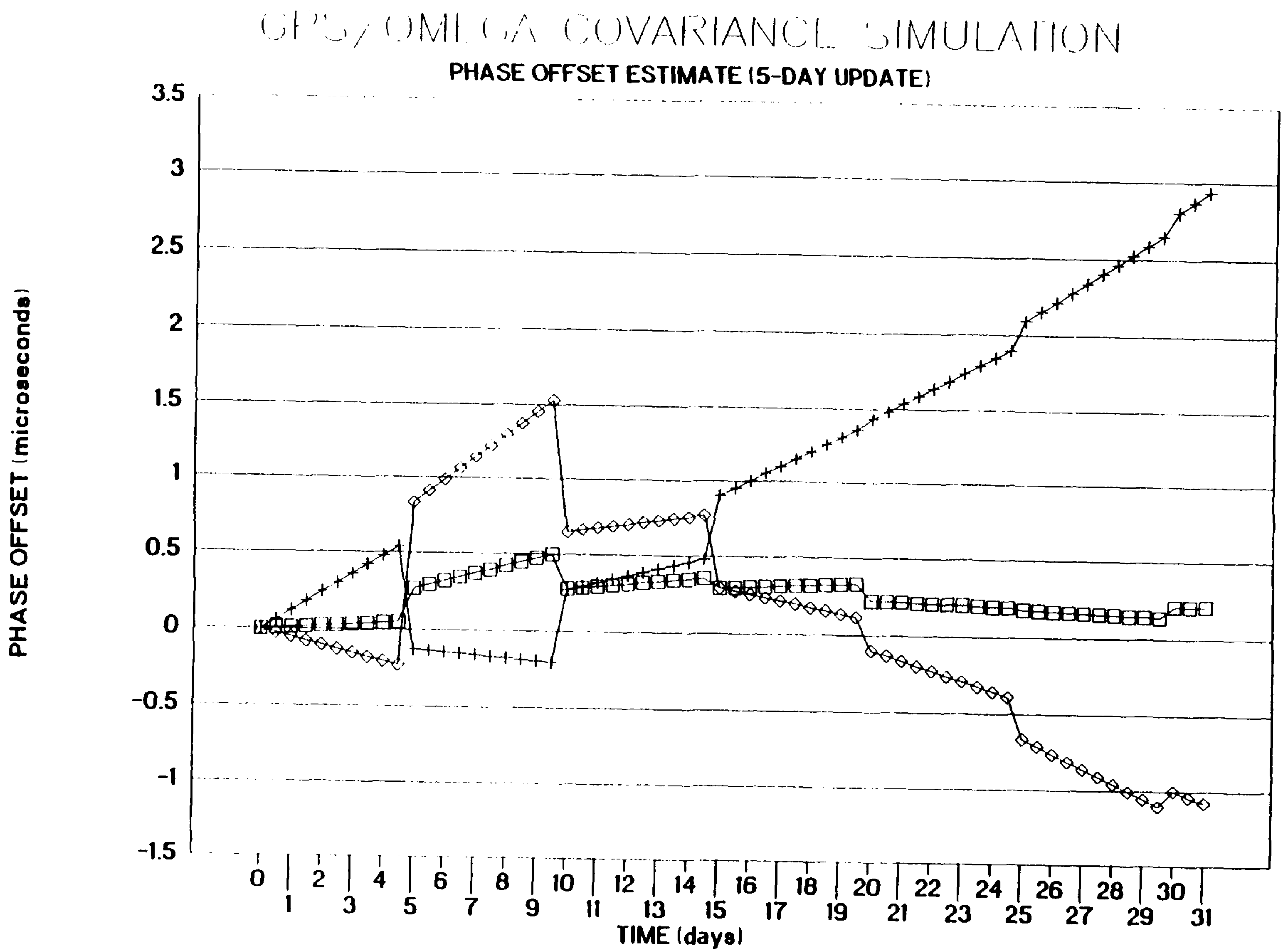
5.1-16 Configuration II - Phase Offset Residual (5 day)



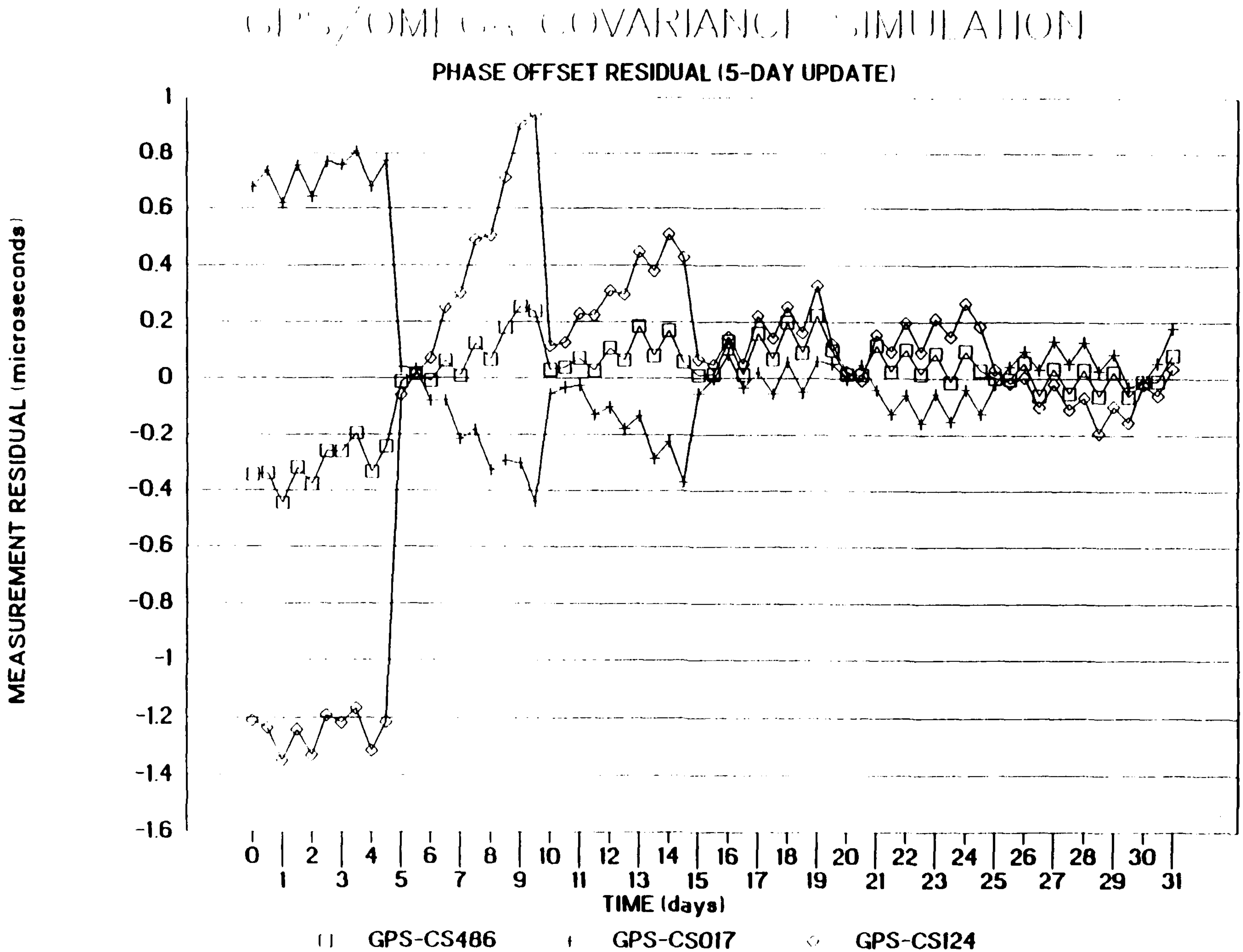
5.1-17 Configuration II - Filter Indicated RMS Phase Offset Errors (5 day)



5.2-1 Sample - Phase Offset Residual (5 day), Hawaii



5.2-2 Transient Response - Phase Offset Estimate (Configuration I)



5.2-3 Transient Response - Phase Offset Residual (Configuration I)

6. <u>REFERENCES</u>

1. "User's Guide for GPS/Omega Covariance Simulation Program", ***SYNETICS*** Corporation, Contract DTCG-23-86-A-20022, April 1990.

2. "Analysis of GPS Timing Data in Support of Omega System Synchronization: A Cesium Stability Study - ADDENDUM", ***SYNETICS*** Corporation, Contract DTCG-23-86-A-20022, April 1990.

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J-191-6

ANALYSIS OF GPS TIMING DATA IN SUPPORT OF OMEGA SYSTEM SYNCHRONIZATION: A CESIUM STABILITY STUDY

ADDENDUM

19 April 1990

Contract No. "DTCG23-86-A-20022"
Task Order 88-0002 (BC725986)
Modification 0002

Prepared for:

United States Coast Guard
Omega Navigation Systems Center
7323 Telegraph Road
Alexandria, VA 22310

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1. INTRODUCTION

To demonstrate the Covariance Simulation Program capabilities, five different configurations were used with data from Omega Stations Norway and Hawaii. Chapters 2 and 3 contain the resulting plots. The organization and content of these chapters are described below.

Chapter 2 begins with the CSP test configuration for Norway Station followed by five sections containing the graphs for the corresponding configuration. Each section is identified by the configuration number and includes an alphabetical list of the plots generated for the particular configuration. All of the configurations were executed at 1 day, 3 day, 5 day and 7 day update rates. Chapter 3 has an identical layout but was generated on a month of data for the Hawaii Station. Chapter 4 includes a source code listing of the main Kalman filter routine, GPSSIM, and the file translation routine, FILEPRC.

2. NORWAY

Table 2-1 depicts five CSP configurations that were used to process RDAS timing data from Omega Station Norway.

Table 2-1
CSP TEST CONFIGURATION
(Norway Station)

CONFIGURATION NO.	GPS TIME TRANSFER	ON-LINE CESIUM (CS486)	PRIMARY CESIUM (CS124)	SECONDARY CESIUM (CS017)
I	On	On	On	On
II	On	On	On	On
III	On	On	Off	On
IV	Off	On	On	On
V	Off	On	Off	On

2.1 CONFIGURATION I

Seven types of plots were generated for this configuration. They are presented in the following order:

a) Phase Offset Estimate

b) Frequency Offset Estimate

c) Phase Offset Residual: GPS-CS486, GPS-CS017, GPS-CS124

d) Phase Covariance

e) Frequency Covariance

This configuration was implemented by the following types of events: GPS1, GPS2 and GPS3. Event "GPS1" identifies GPS-CS486 measurement; event "GPS2" identifies GPS-CS017 measurement and event "GPS3" identifies GPS-CS124 measurement. The remainder of this section contains plots as described above.

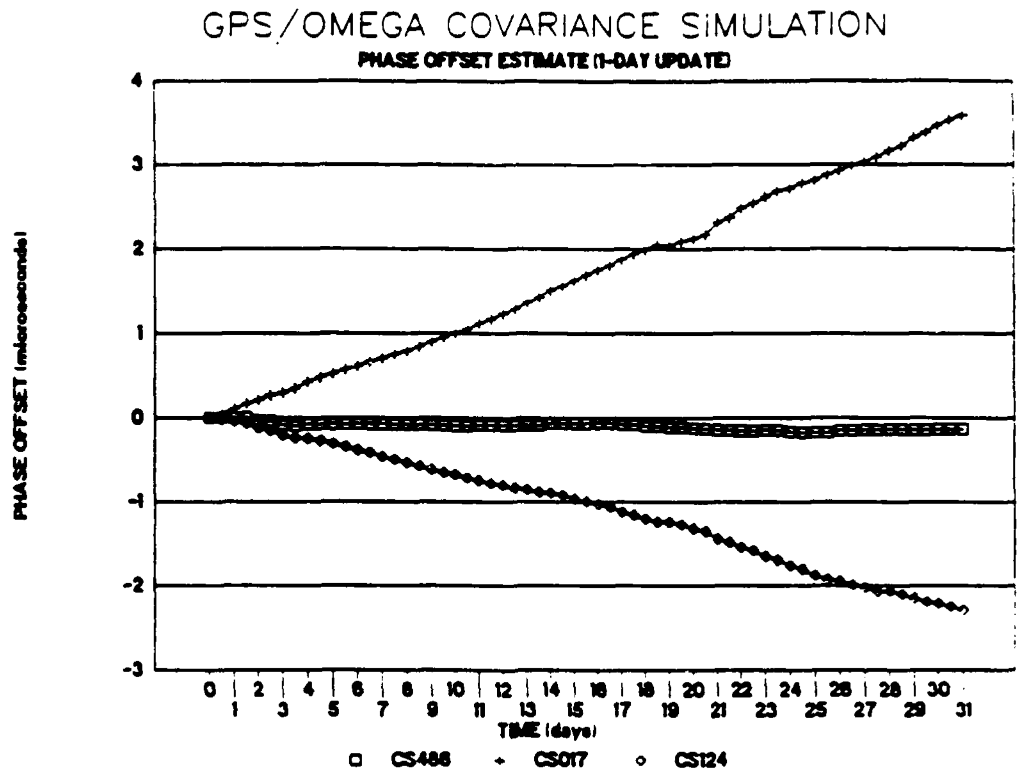


Figure 2.1-1a Phase Offset Estimate (1 Day Update)

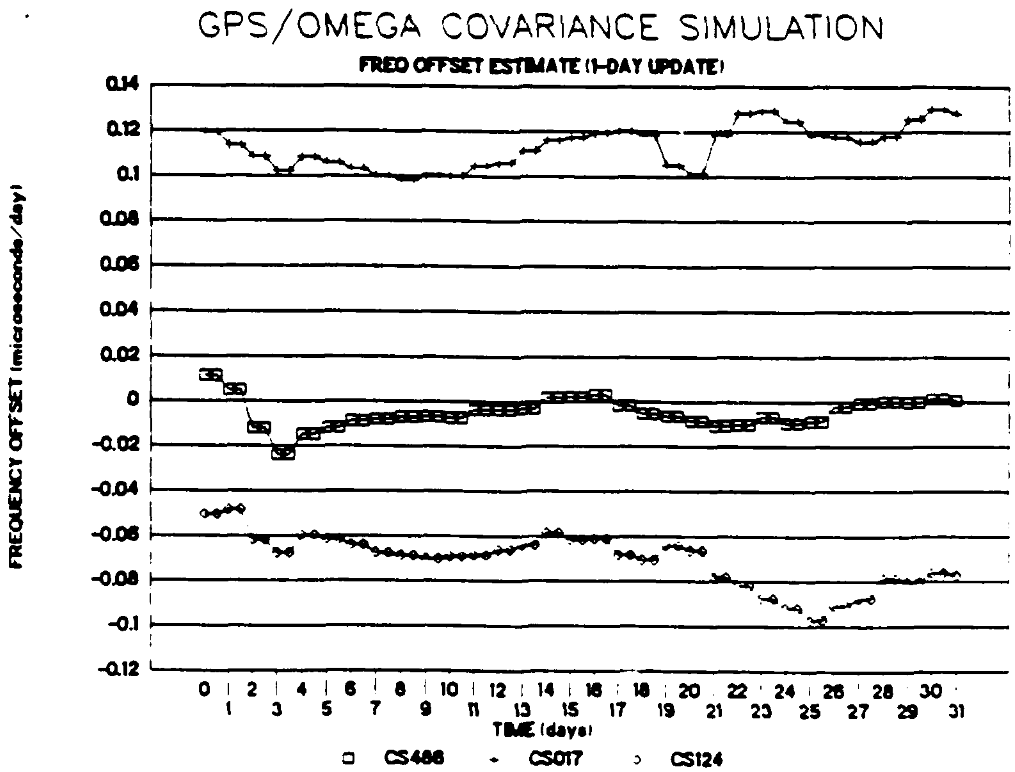


Figure 2.1-1b Frequency Offset Estimate (1 Day Update)

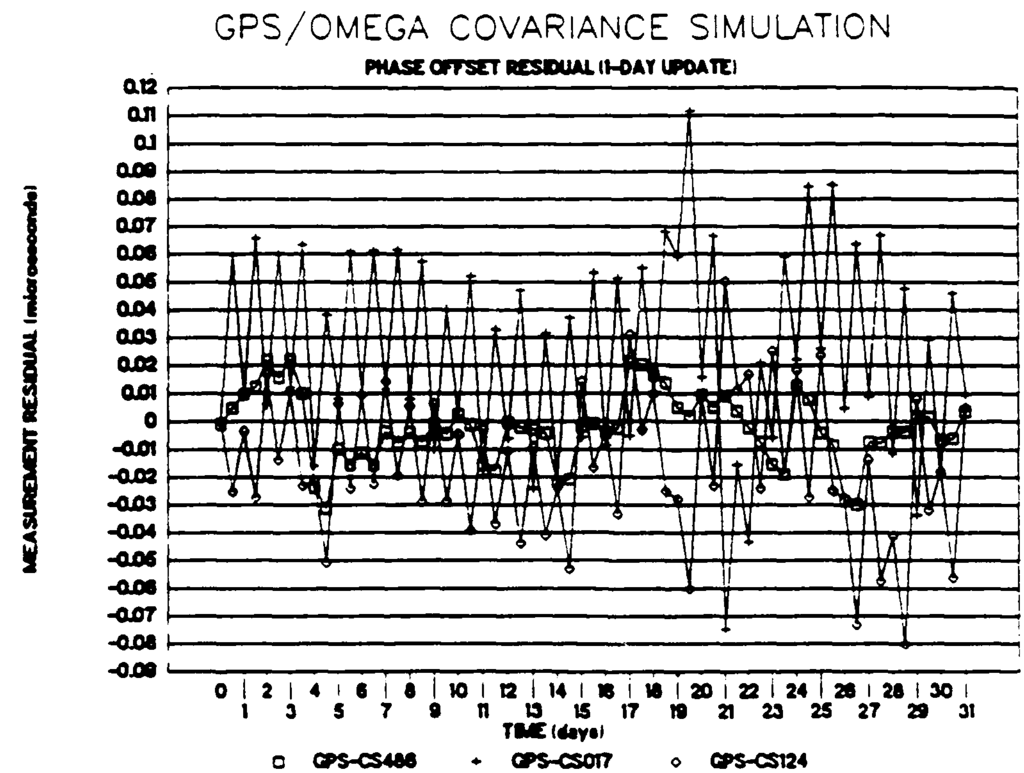


Figure 2.1-1c Phase Offset Residual: GPS-CS486,-CS017,-CS124 (1 Day Update)

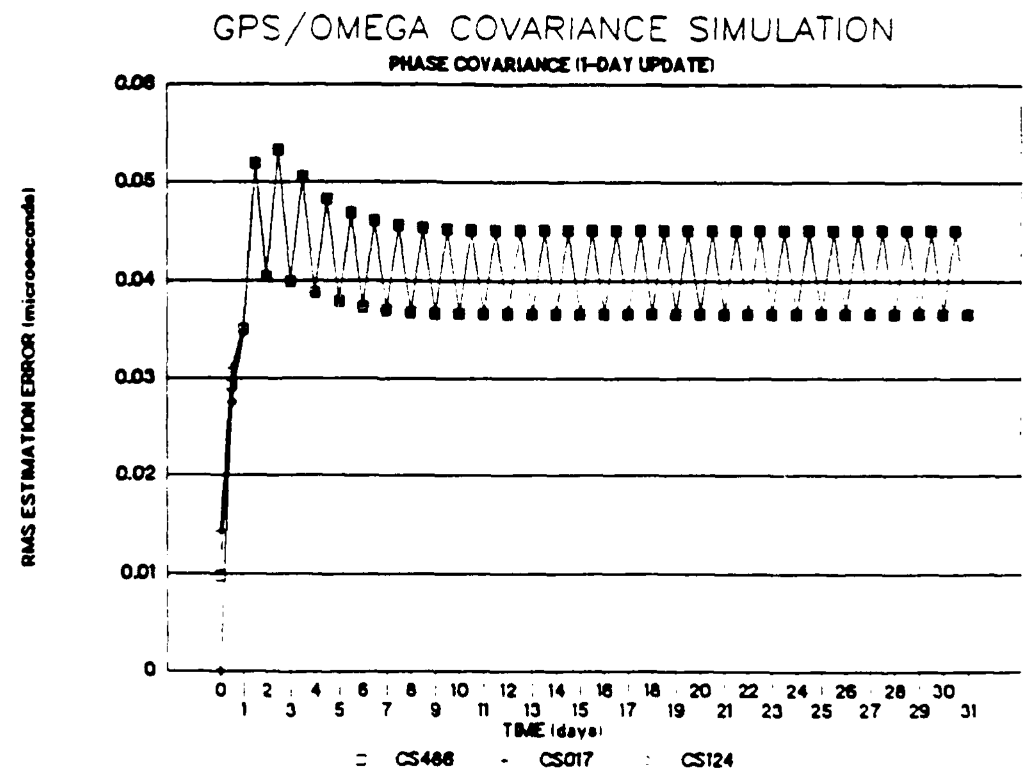


Figure 2.1-1d Phase Covariance (1 Day Update)

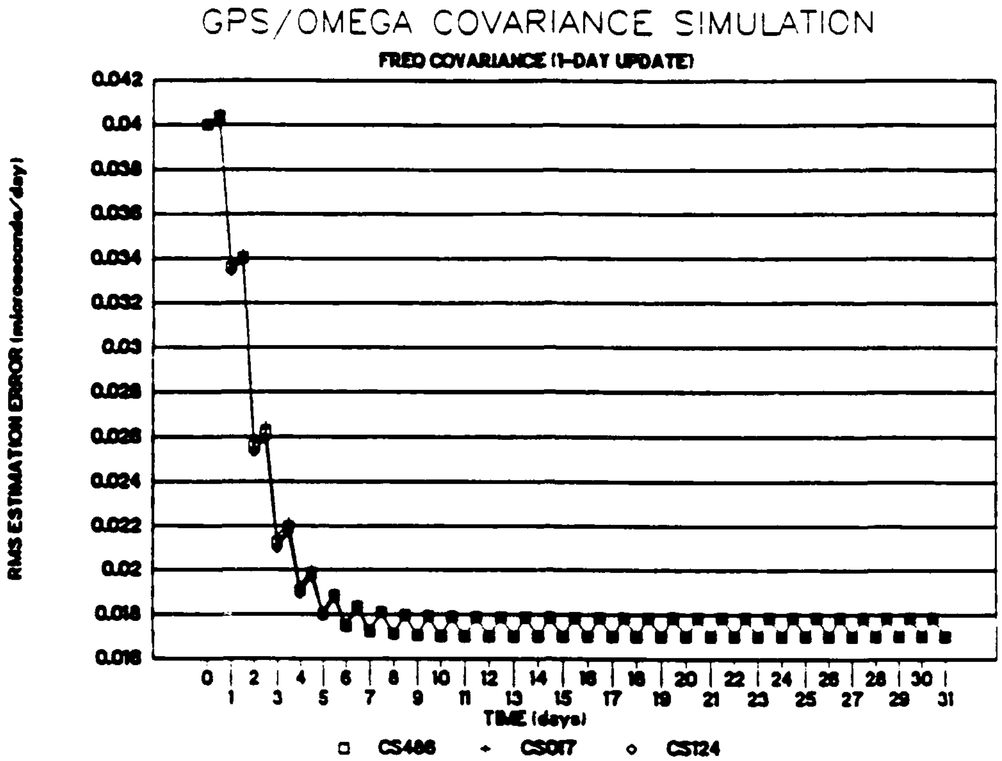


Figure 2.1-1e Frequency Covariance (1 Day Update)

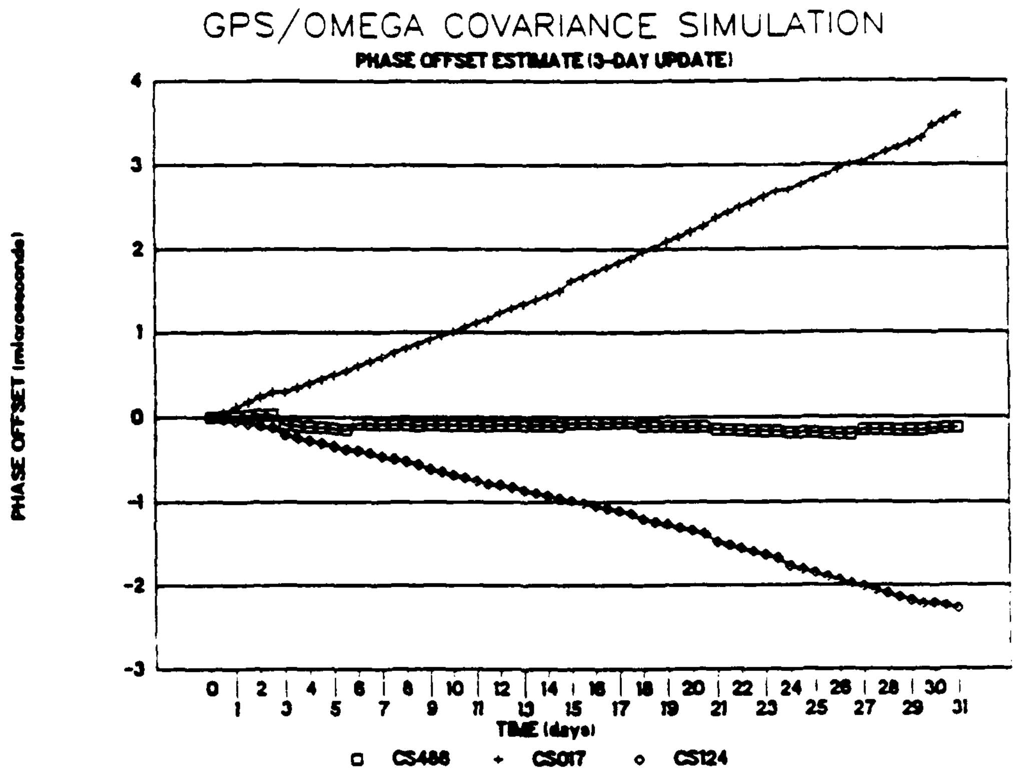


Figure 2.1-2a Phase Offset Estimate (3 Day Update)

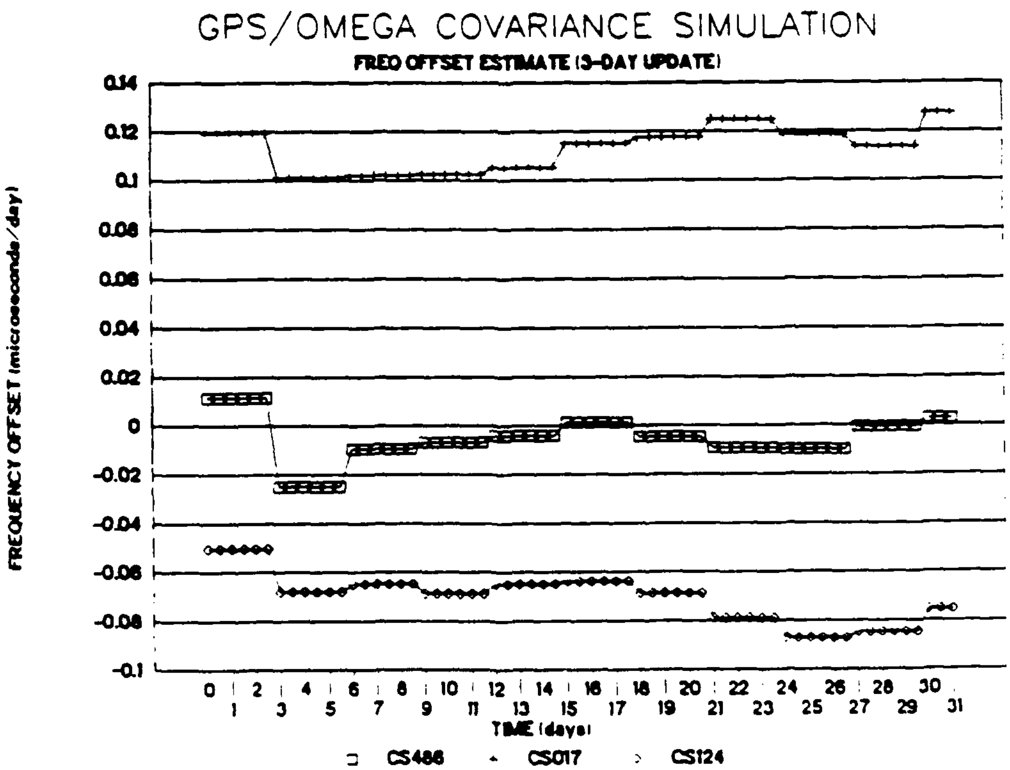


Figure 2.1-2b Frequency Offset Estimate (3 Day Update)

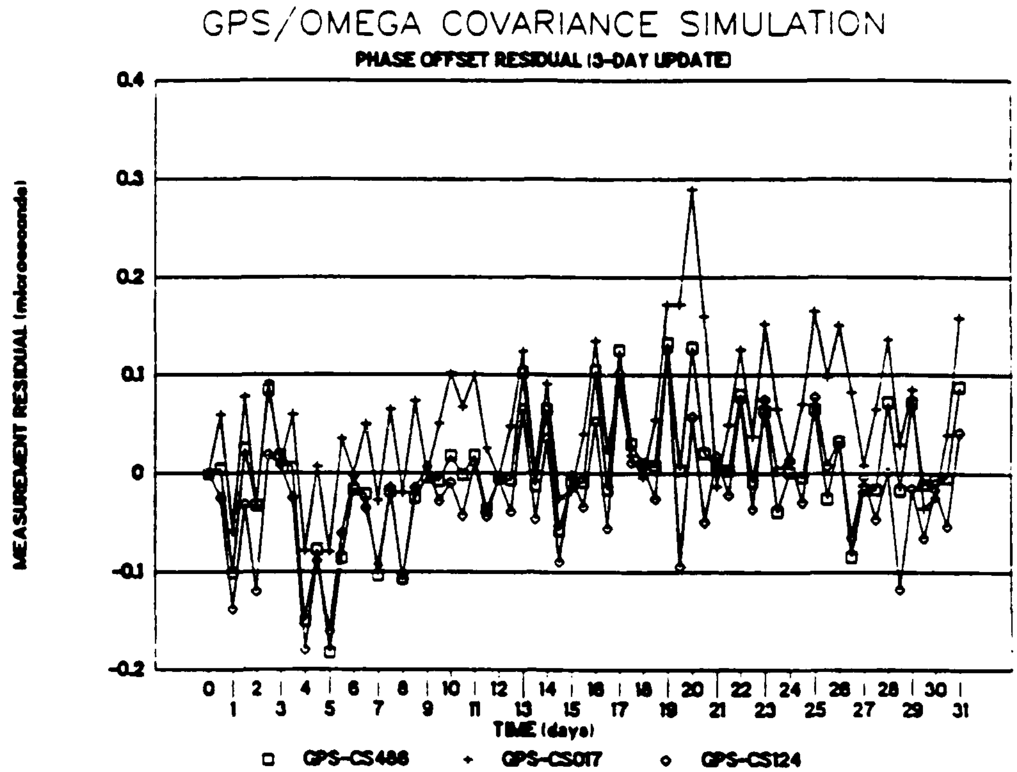


Figure 2.1-2c Phase Offset Residual: GPS-CS486,-CS017,-CS124 (3 Day Update)

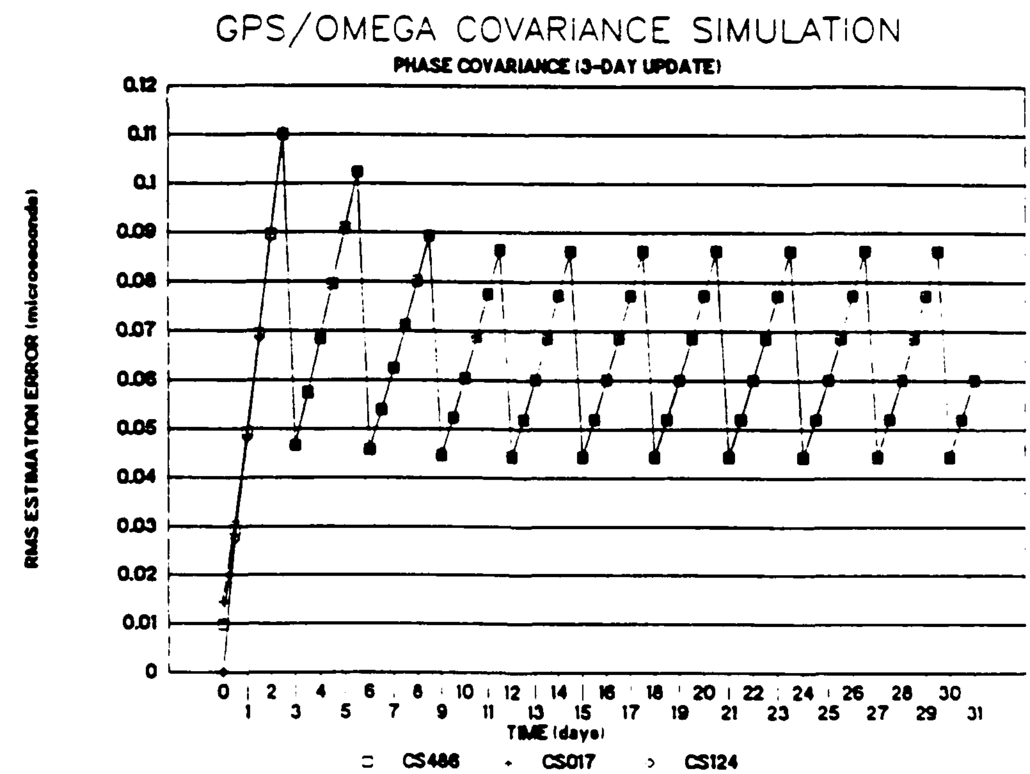


Figure 2.1-2d Phase Covariance (3 Day Update)

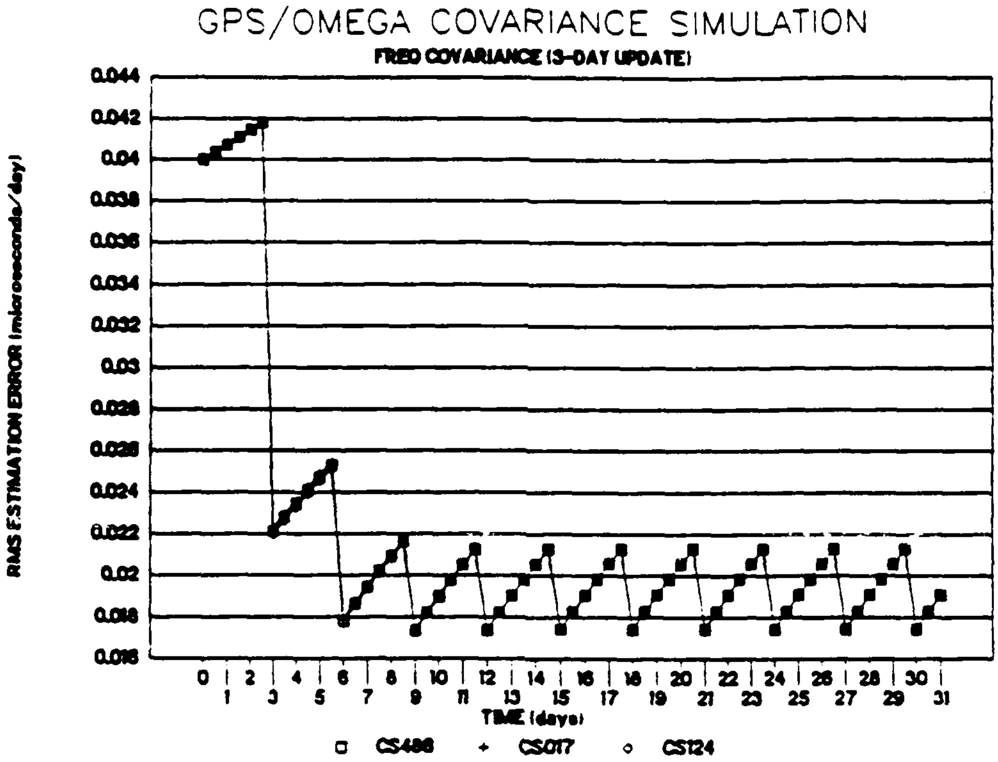


Figure 2.1-2e Frequency Covariance (3 Day Update)

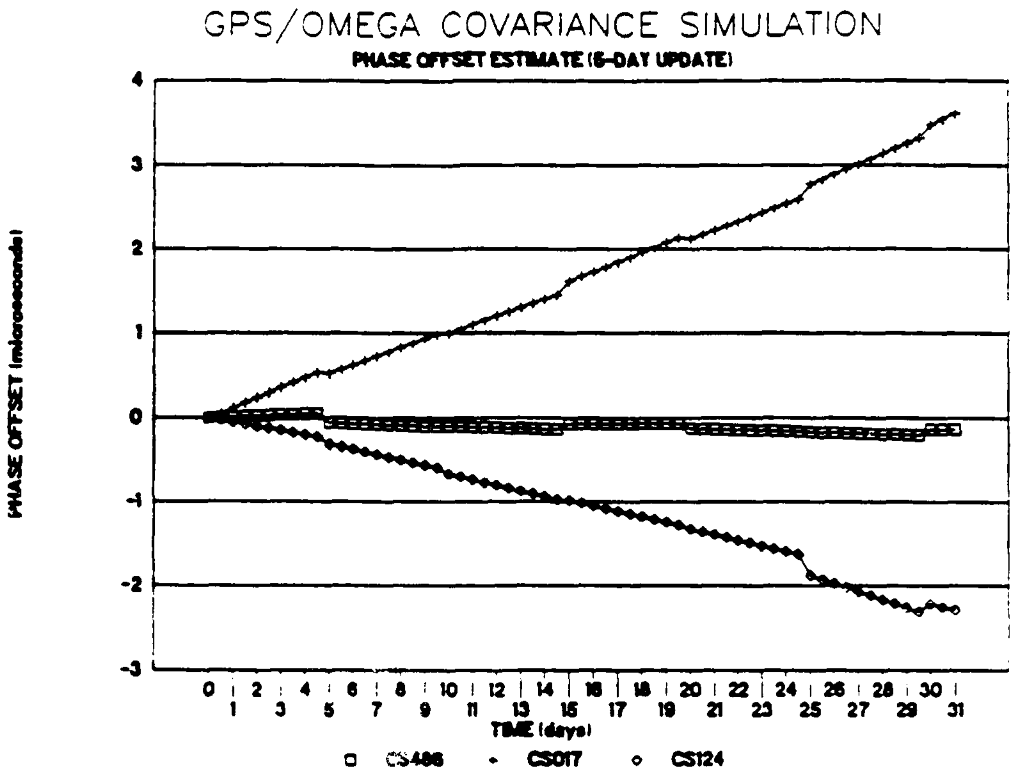


Figure 2.1-3a Phase Offset Estimate (5 Day Update)

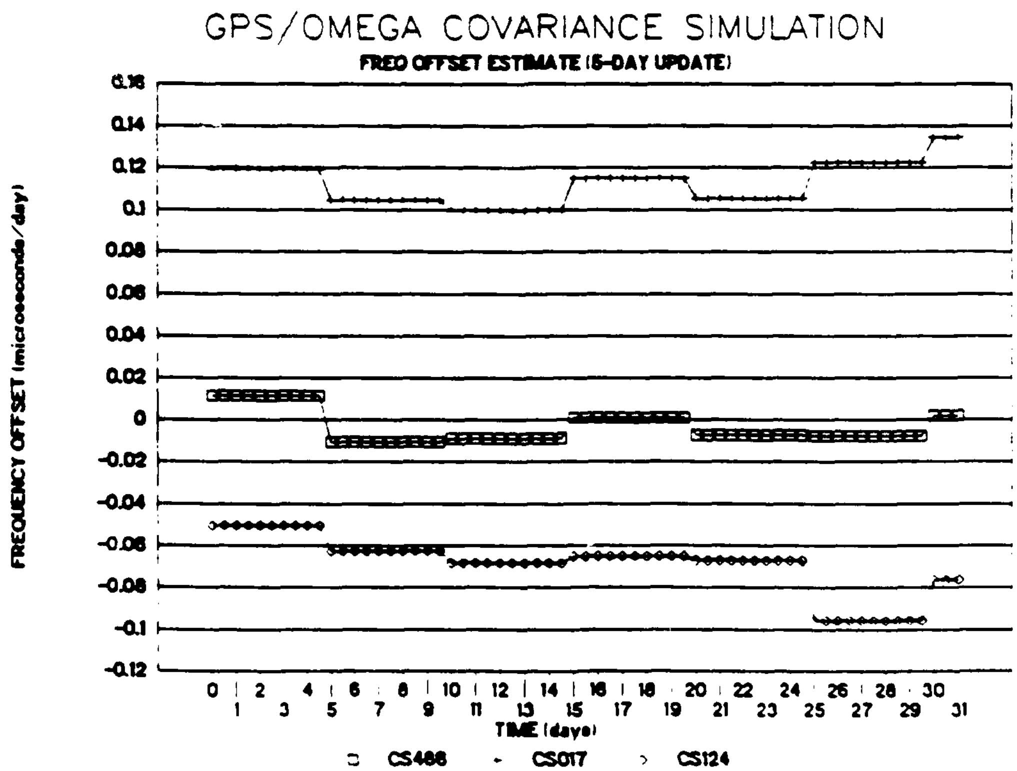


Figure 2.1-3b Frequency Offset Estimate (5 Day Update)

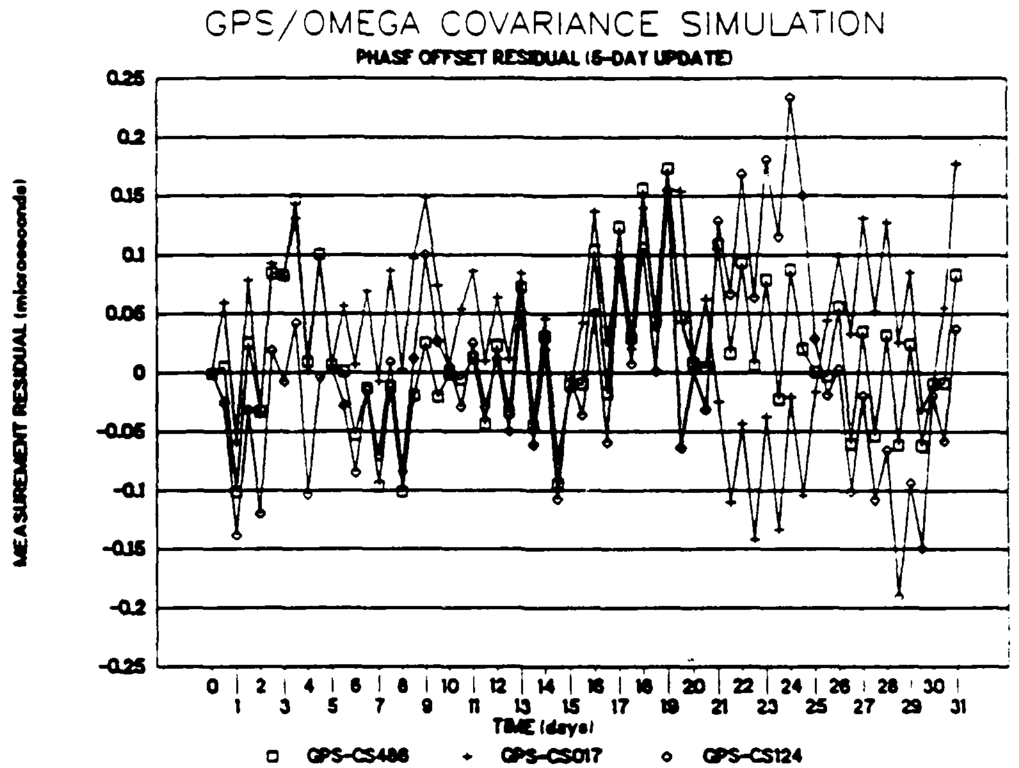


Figure 2.1-3c Phase Offset Residual: GPS-CS486,-CS017,-CS124 (5 Day Update)

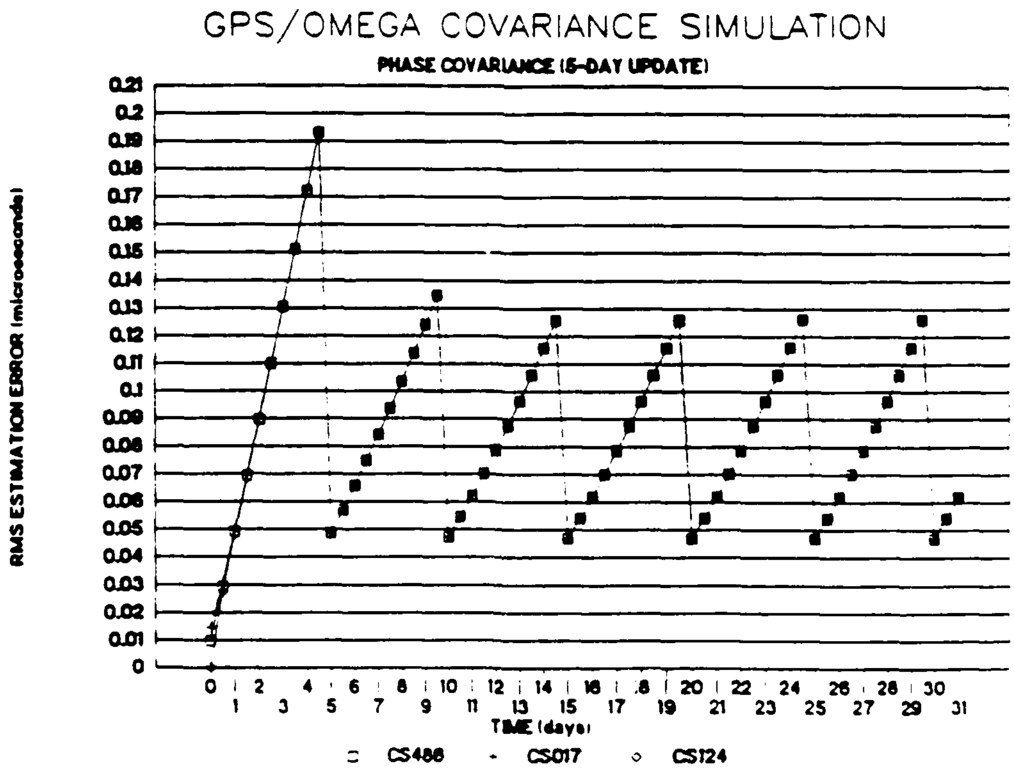


Figure 2.1-3d Phase Covariance (5 Day Update)

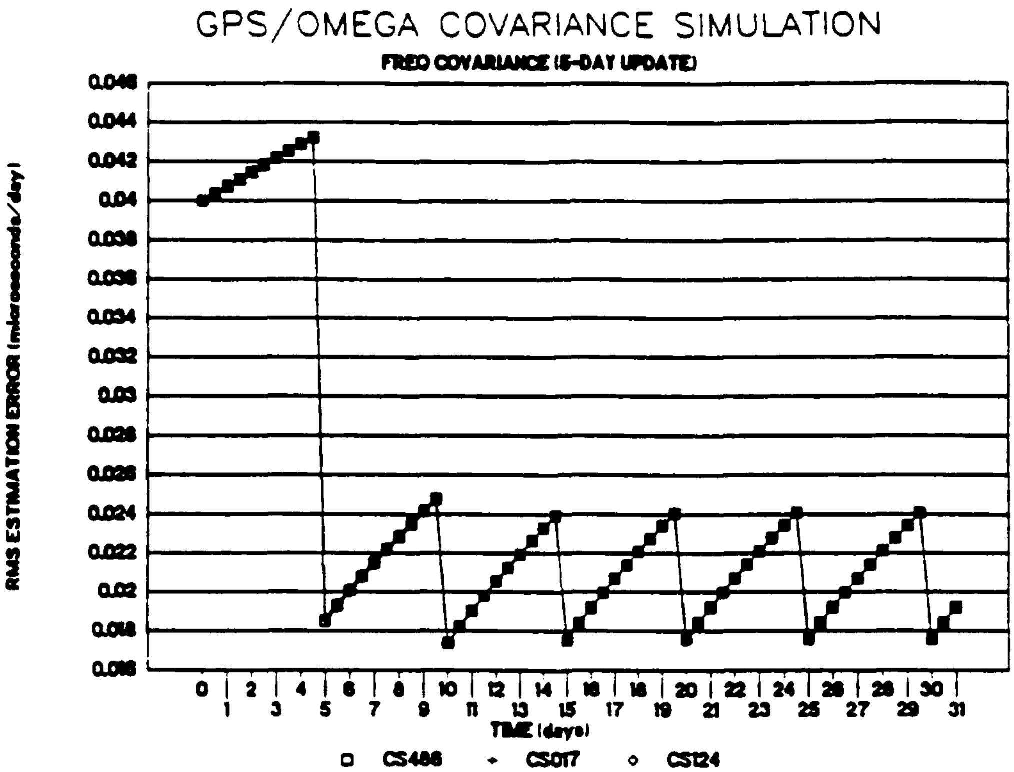


Figure 2.1-3e Frequency Covariance (5 Day Update)

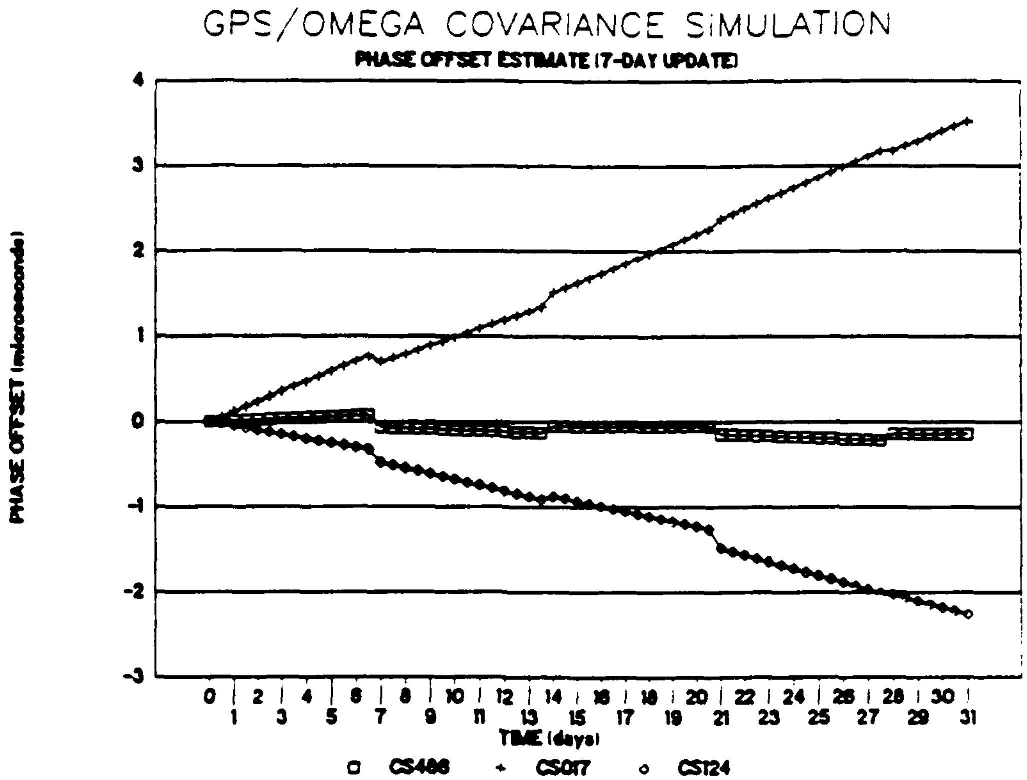


Figure 2.1-4a Phase Offset Estimate (7 Day Update)

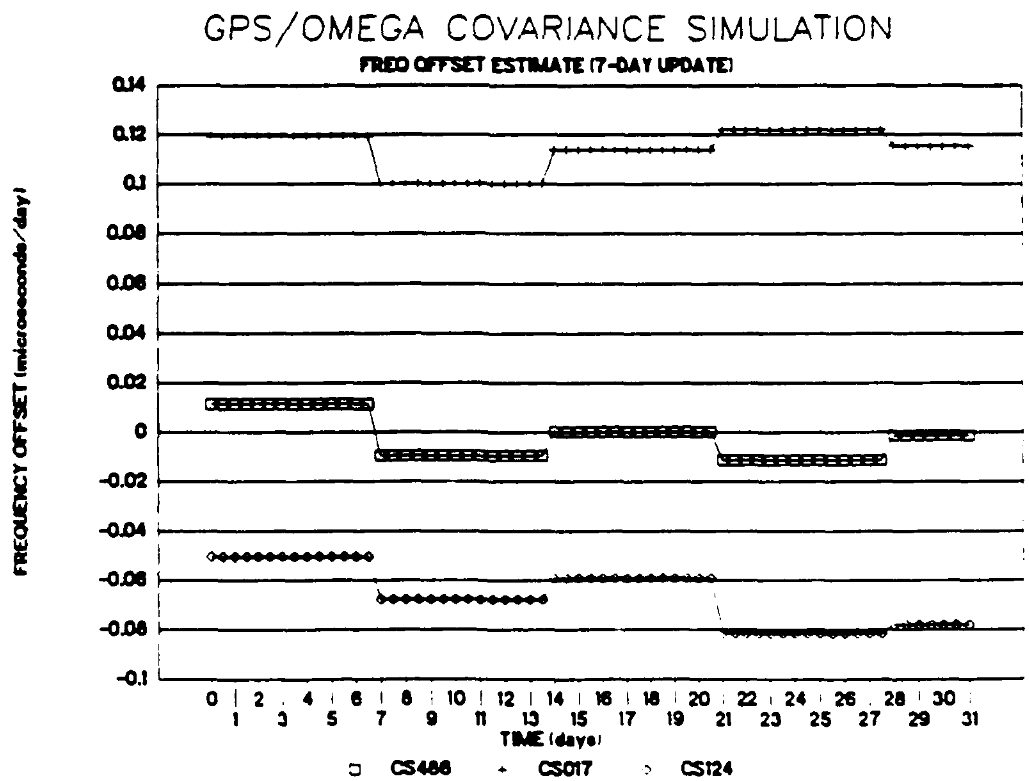


Figure 2.1-4b Frequency Offset Estimate (7 Day Update)

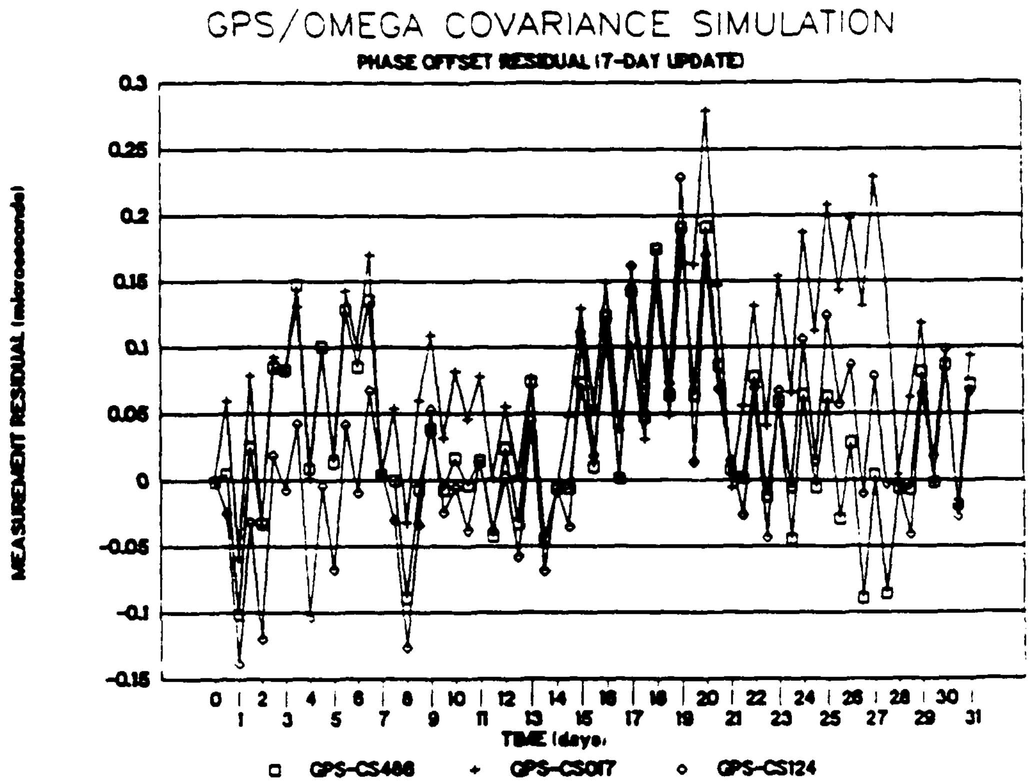


Figure 2.1-4c Phase Offset Residual: GPS-CS486,-CS017,-CS124 (7 Day Update)

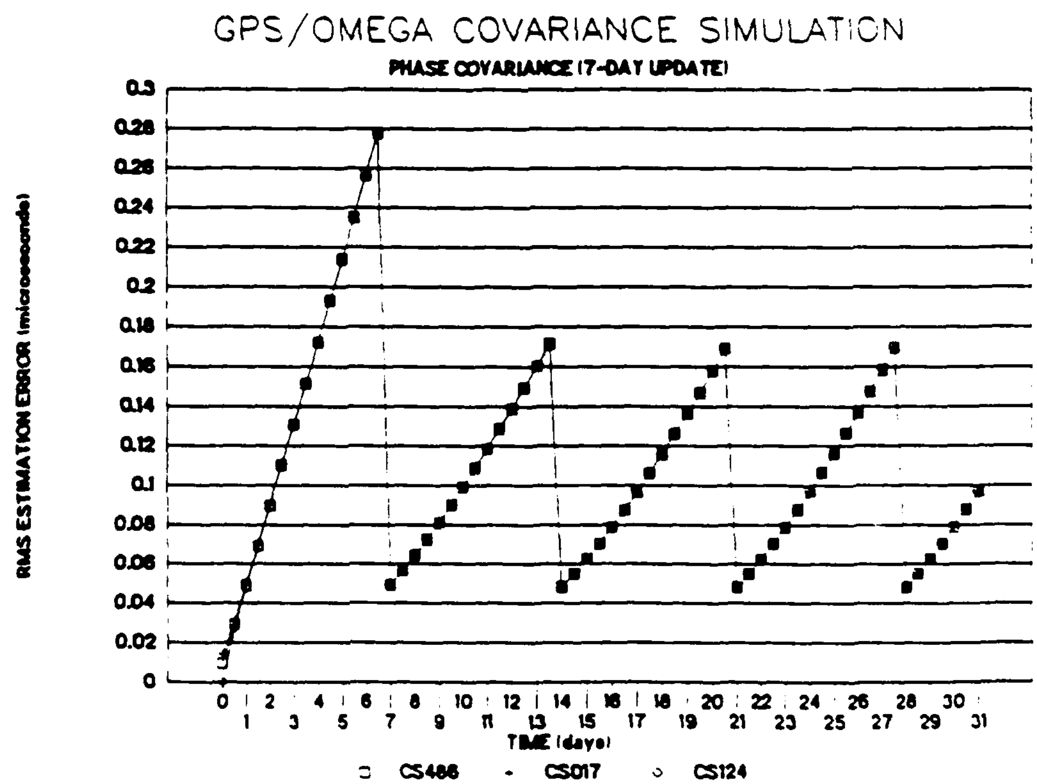


Figure 2.1-4d Phase Covariance (7 Day Update)

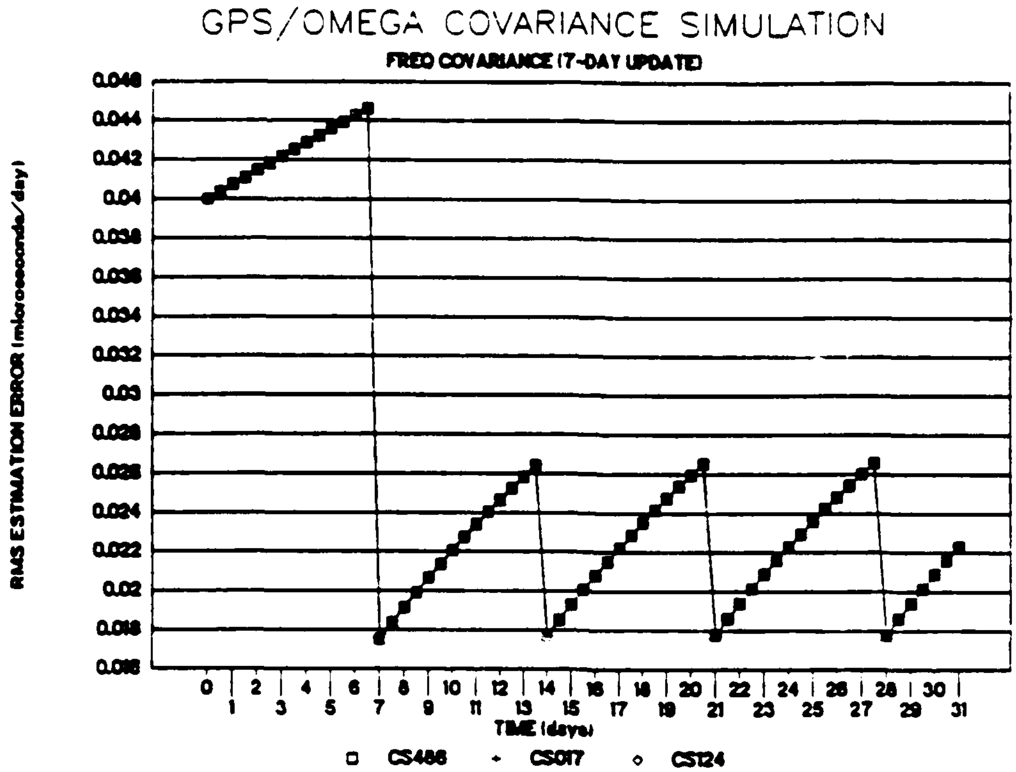


Figure 2.1-4e Frequency Covariance (7 Day Update)

2.2 CONFIGURATION II

Five types of plots were generated for this configuration. They are presented in the following order:

a) Phase Offset Estimate

b) Phase Offset Residual: GPS-CS486, GPS-CS017, GPS-CS124

c) Phase Covariance

This configuration was implemented by the following types of events: GPS1, CLK1 and CLK2. Event "GPS1" identifies GPS-CS486 measurement; event "CLK1" identifies CS486-CS017 measurement and event "CLK2" identifies CS486-CS124 measurement. The remainder of this section contains plots as described above.

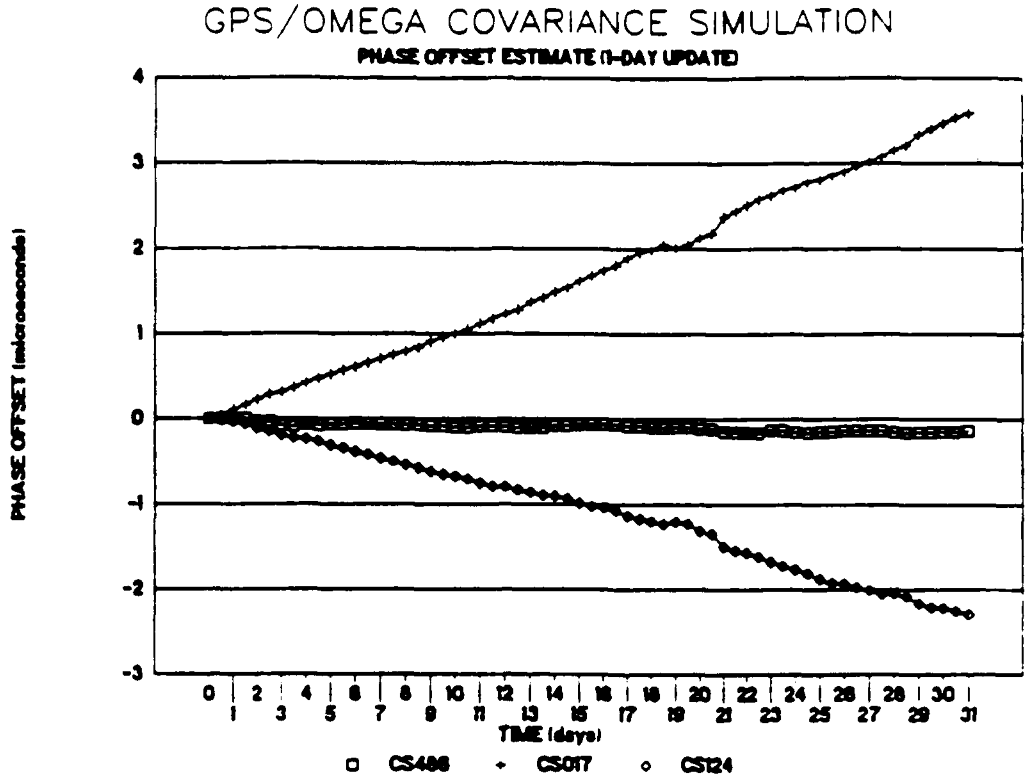


Figure 2.2-1a Phase Offset Estimate (1 Day Update)

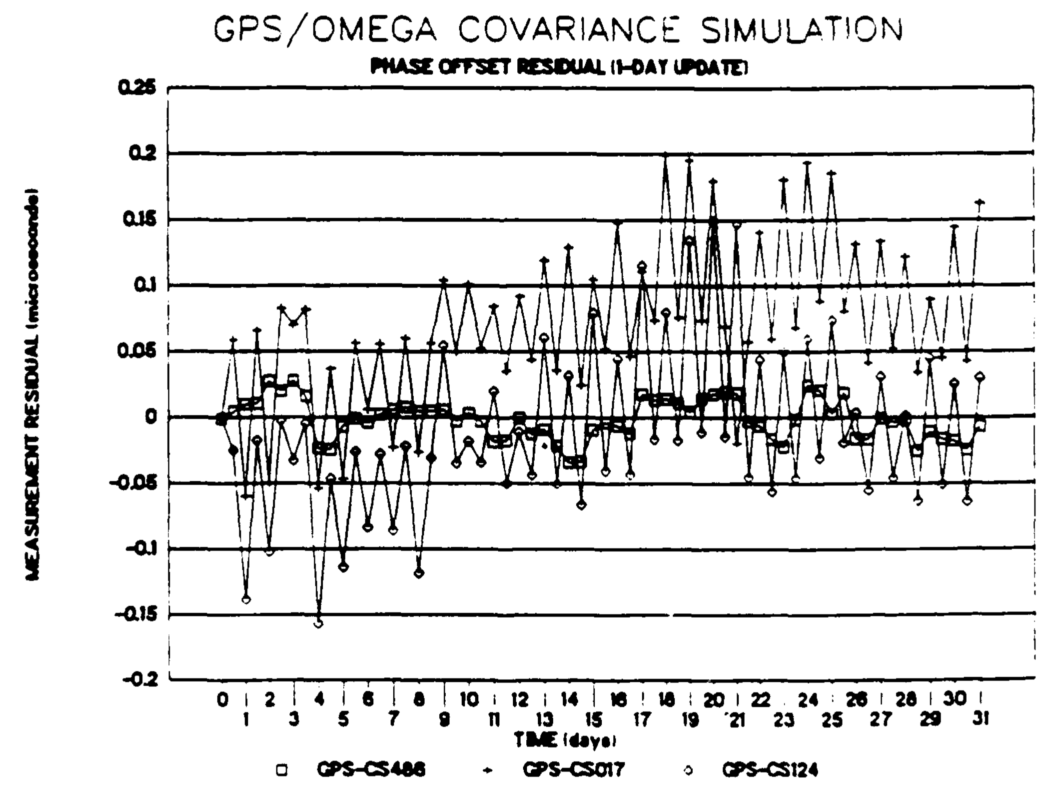


Figure 2.2-1b Phase Offset Residual: GPS-CS486,-CS017,-CS124 (1 Day Update)

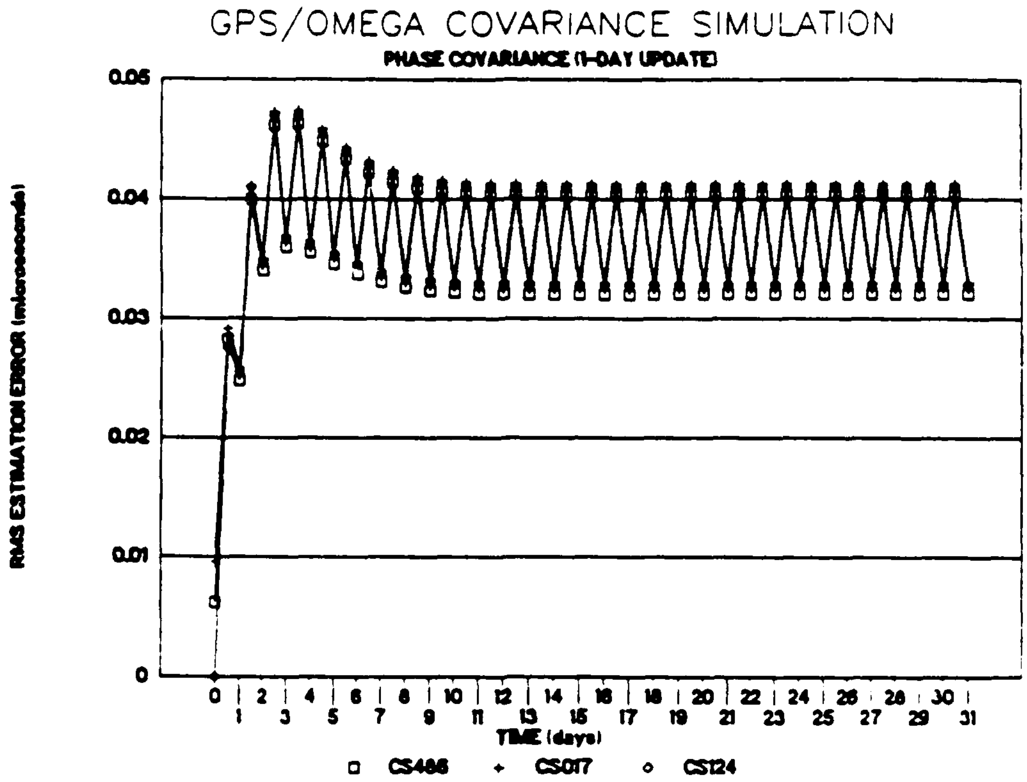


Figure 2.2-1c Phase Covariance (1 Day Update)

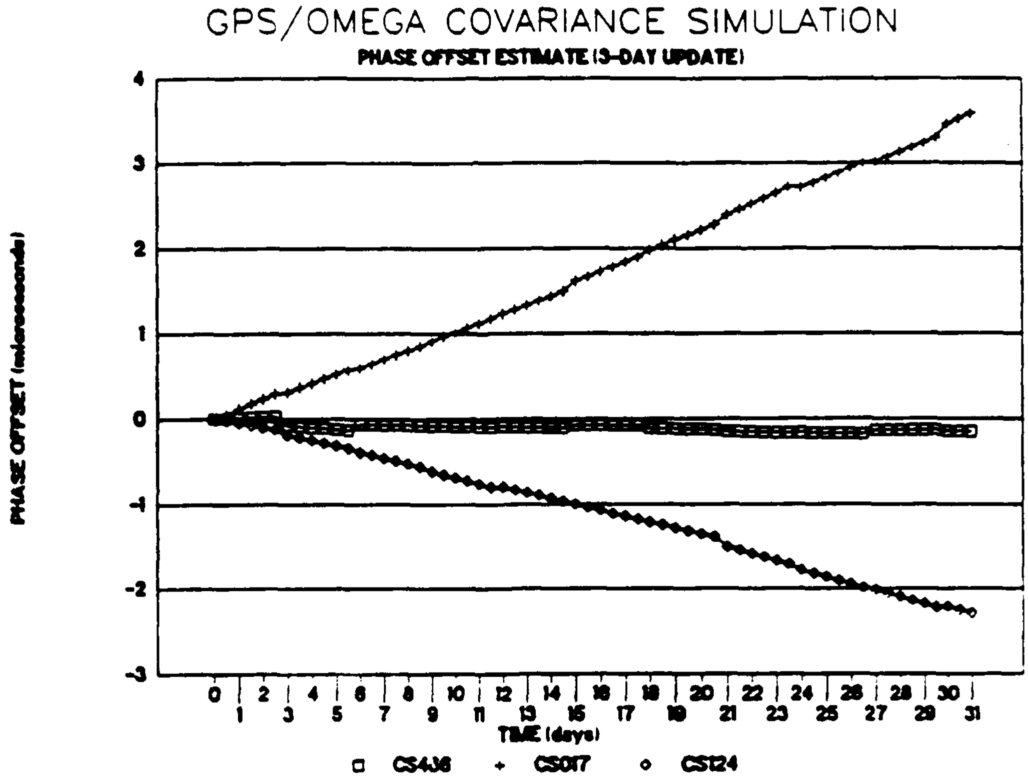


Figure 2.2-2a Phase Offset Estimate (3 Day Update)

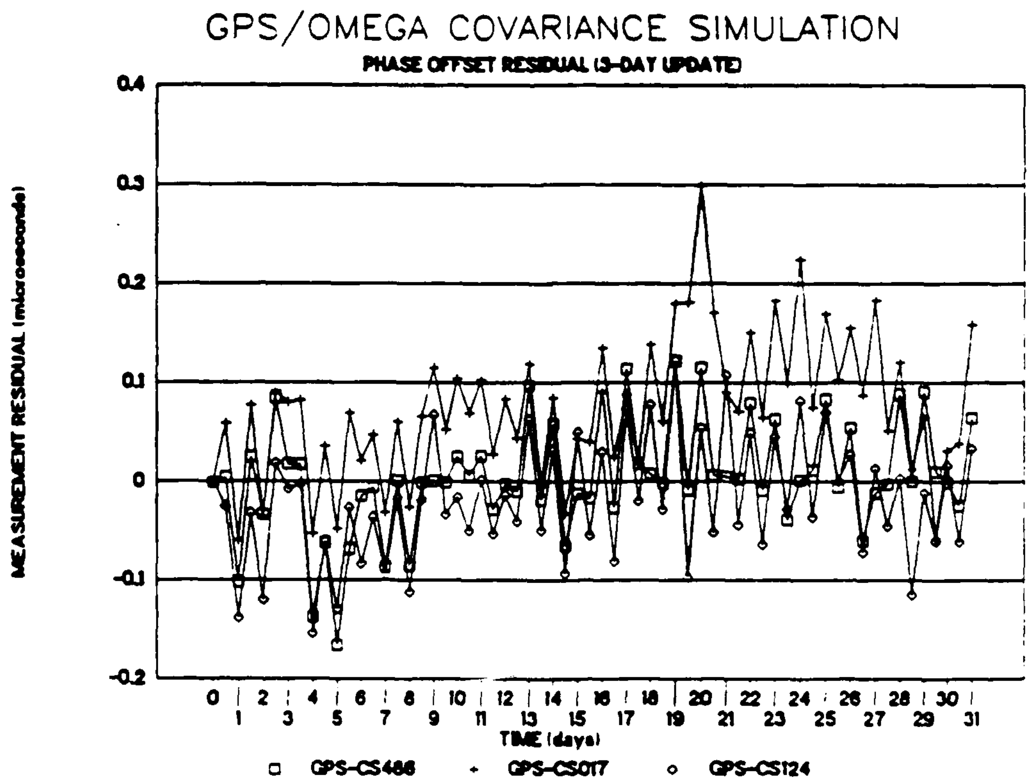


Figure 2.2-2b Phase Offset Residual: GPS-CS486,-CS017,-CS124 (3 Day Update)

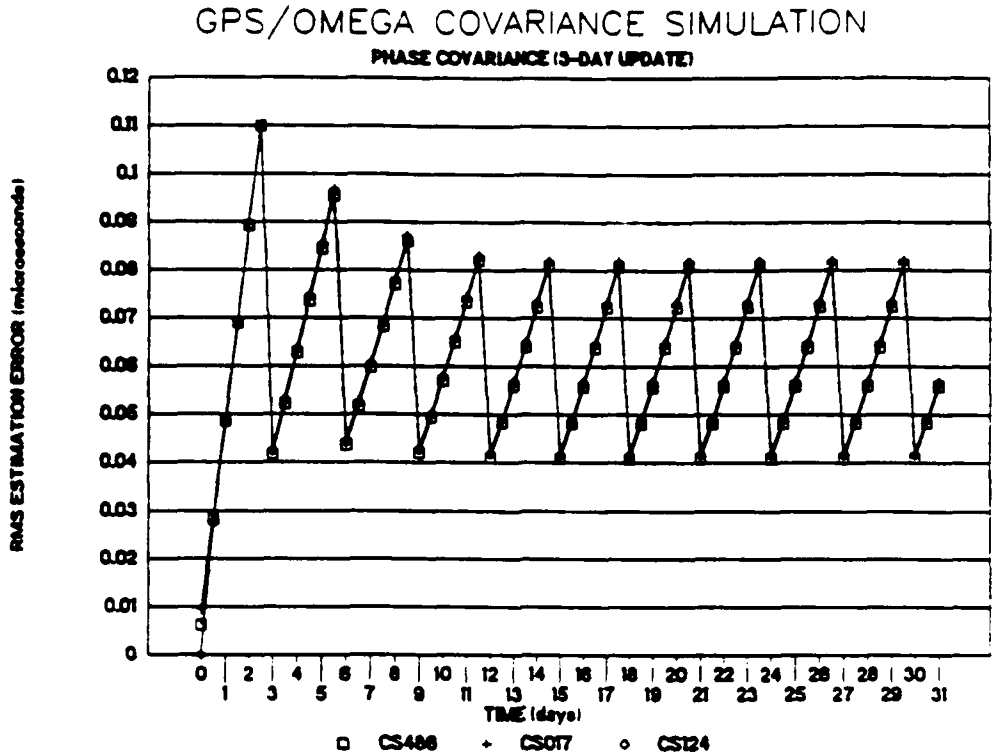


Figure 2.2-2c Phase Covariance (3 Day Update)

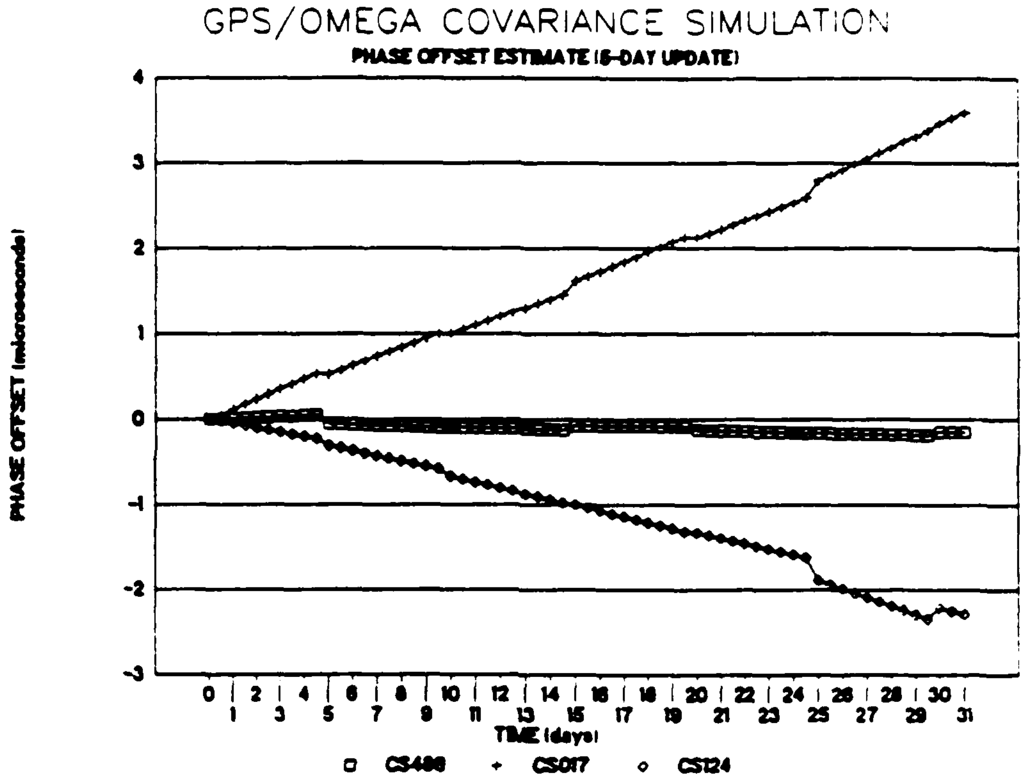


Figure 2.2-3a Phase Offset Estimate (5 Day Update)

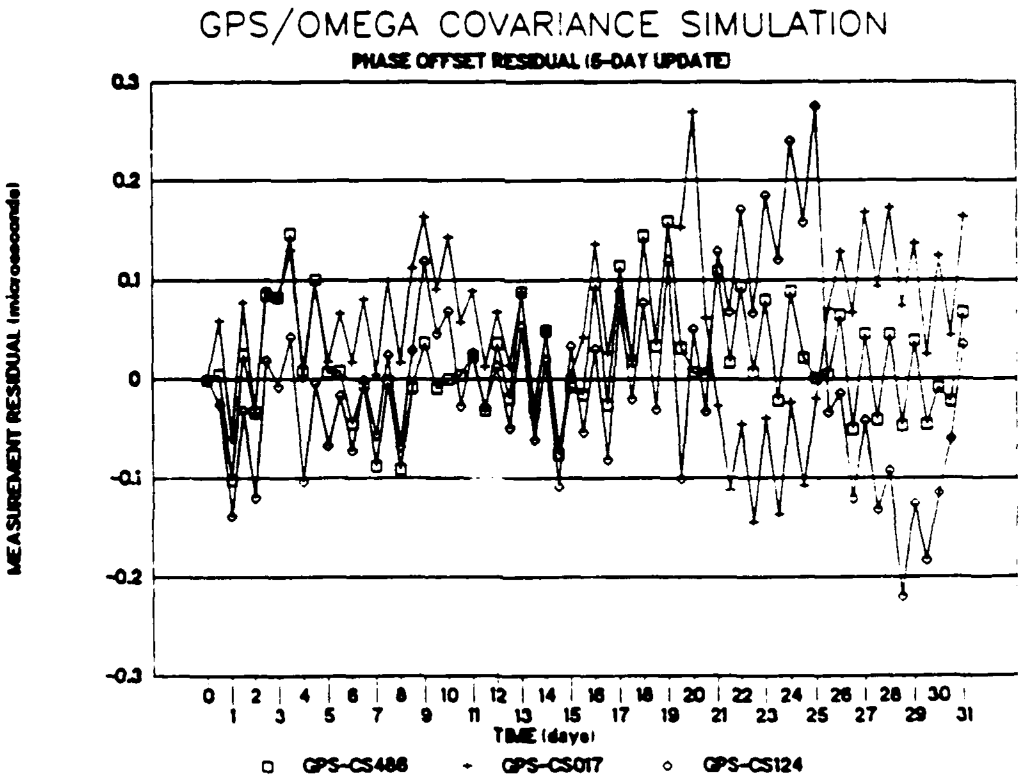


Figure 2.2-3b Phase Offset Residual: GPS-CS486,-CS017,-CS124 (5 Day Update)

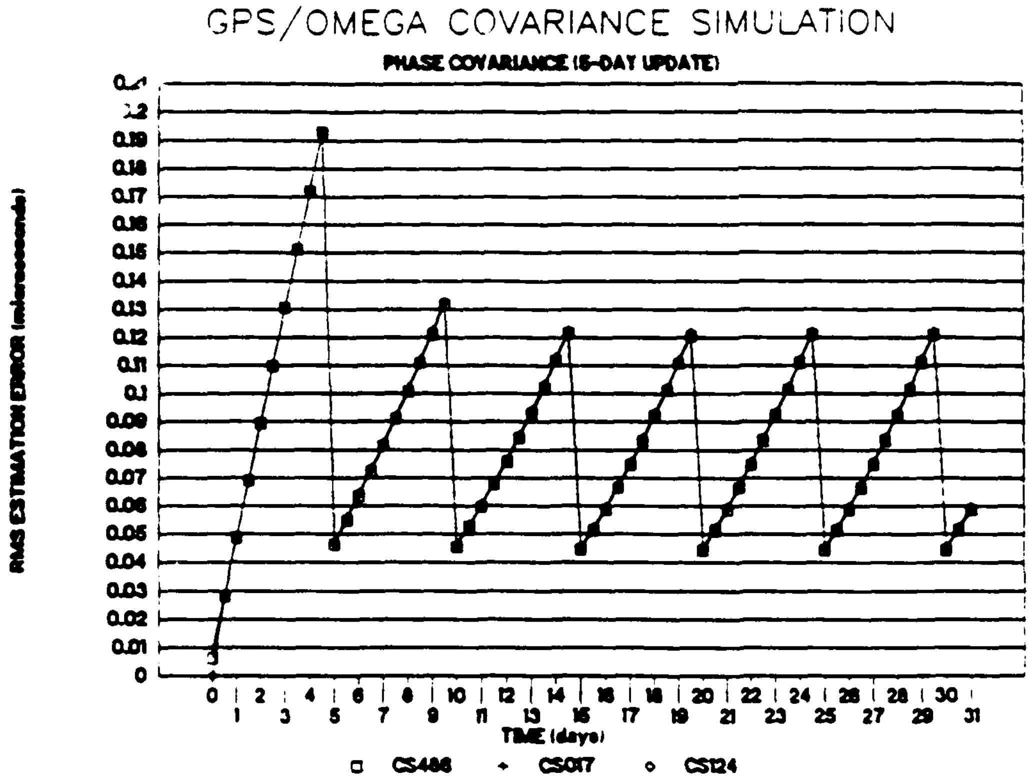


Figure 2.2-3c Phase Covariance (5 Day Update)

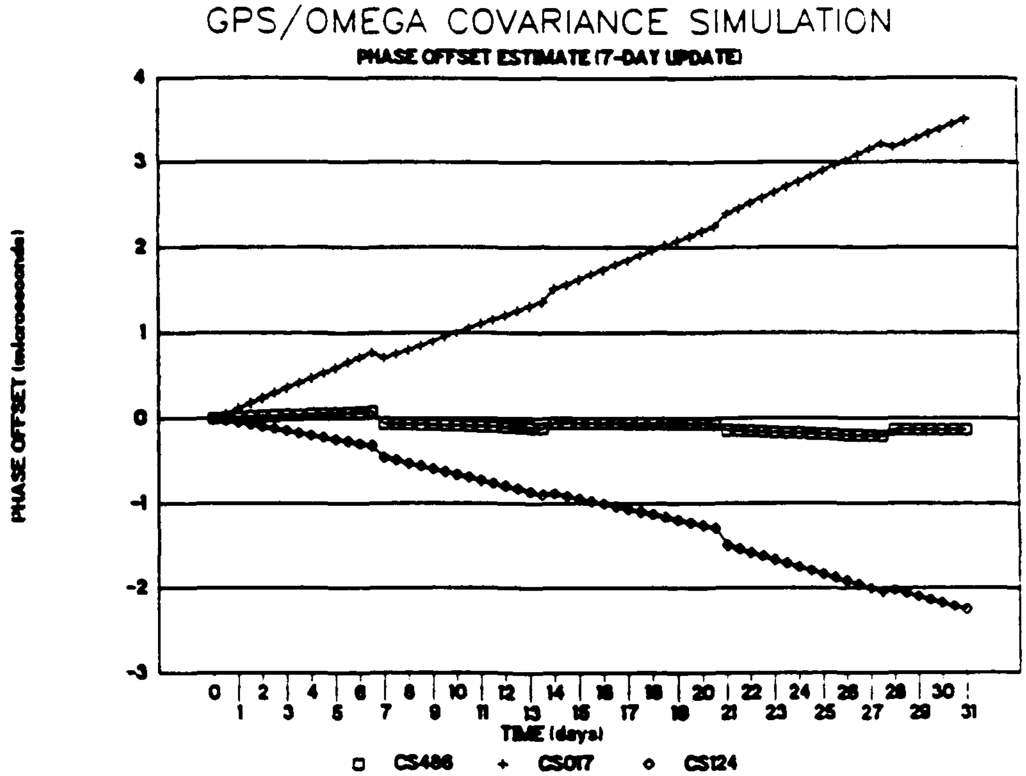


Figure 2.2-4a Phase Offset Estimate (7 Day Update)

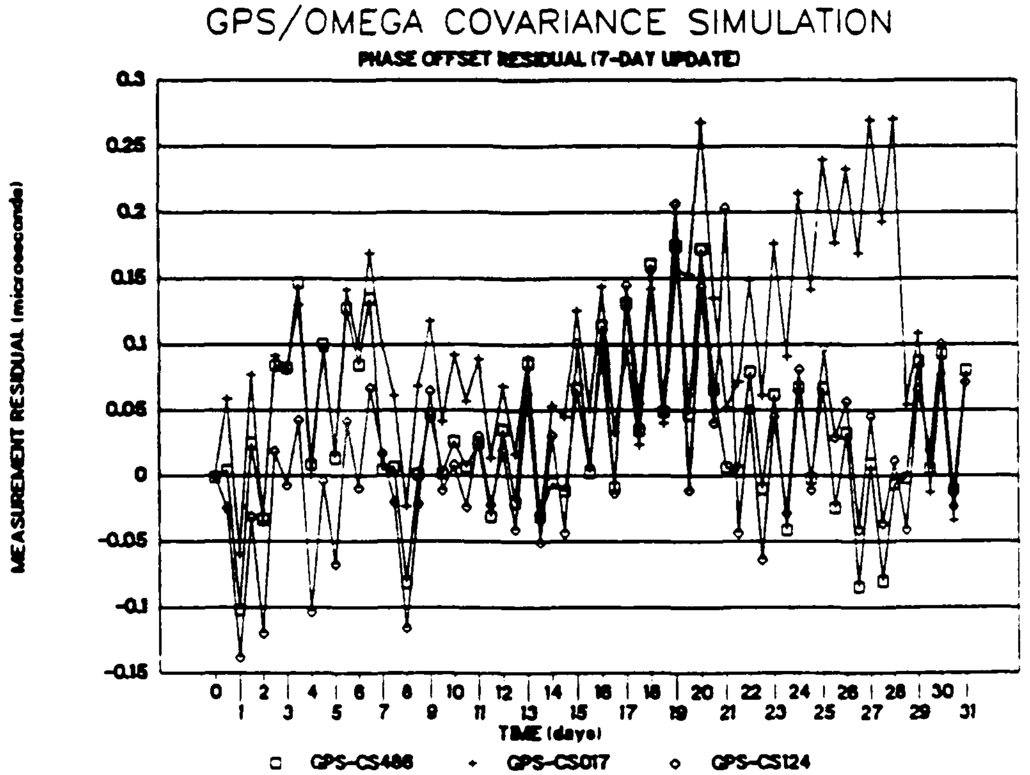


Figure 2.2-4b Phase Offset Residual: GPS-CS486,-CS017 (7 Day Update)

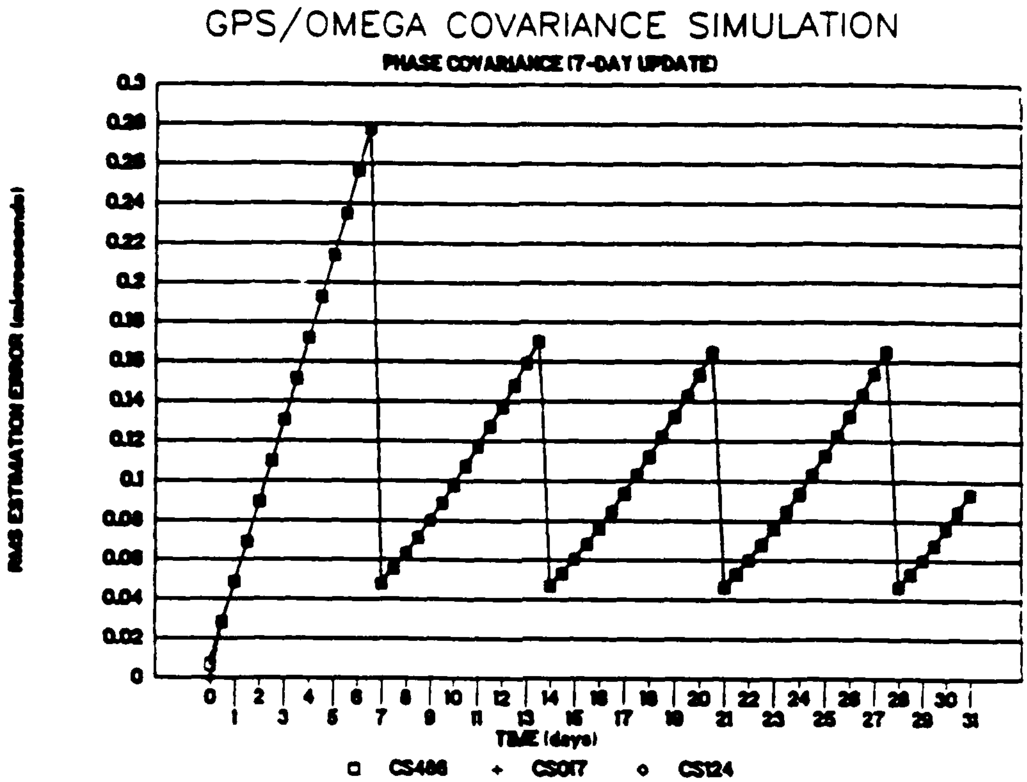


Figure 2.2-4e Phase Covariance (7 Day Update)

2.3 CONFIGURATION III

Three types of plots were generated for this configuration. They are presented in the following order:

a) Phase Offset Estimate

b) Phase Offset Residual: GPS-CS486, GPS-CS017

c) Phase Covariance

This configuration was implemented by the following types of events: GPS1 and CLK1. Event "GPS1" identifies GPS-CS486 measurement and event "CLK1" identifies CS486-CS017 measurement. The remainder of this section contains plots as described above.

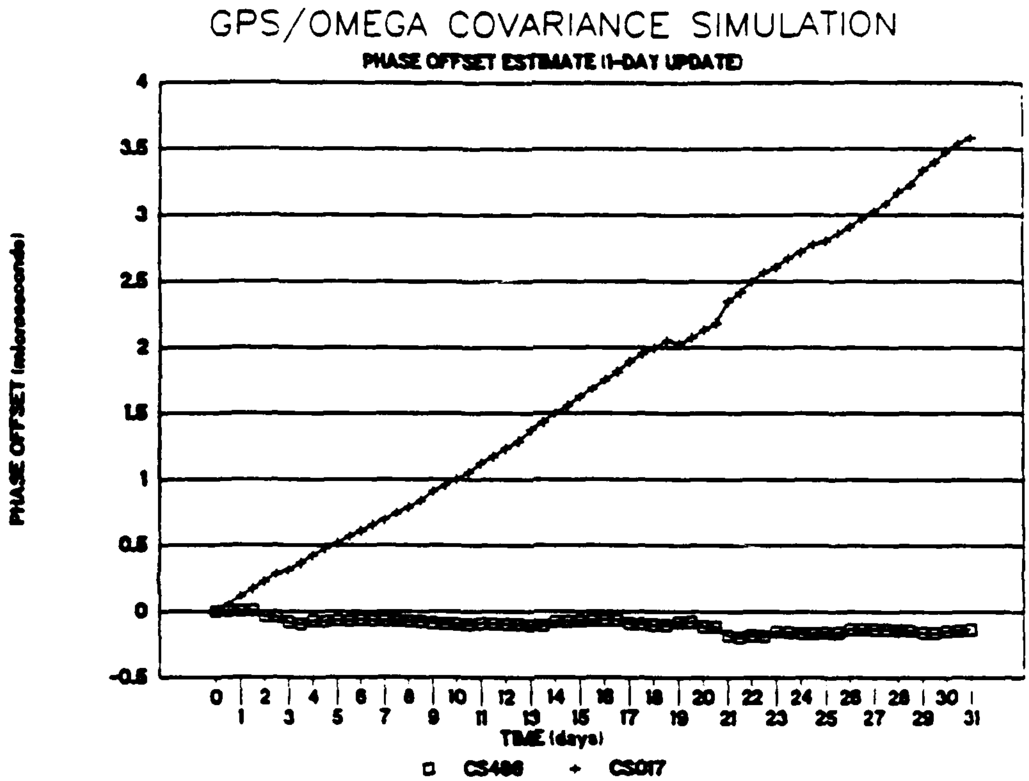


Figure 2.3-1a Phase Offset Estimate (1 Day Update)

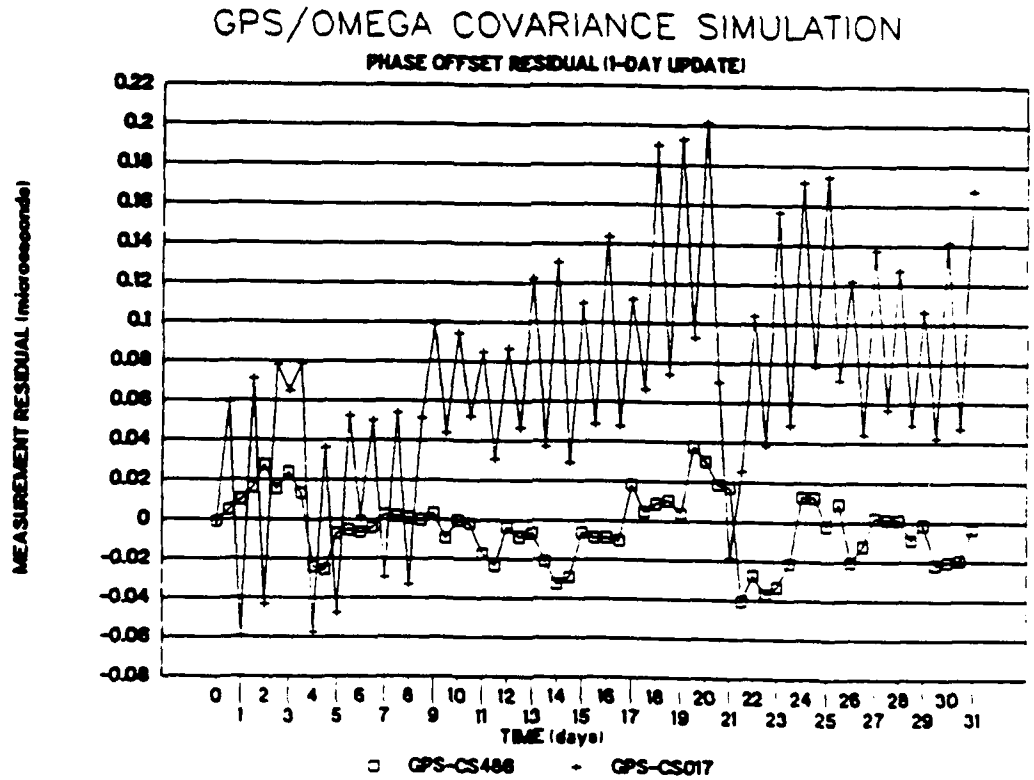


Figure 2.3-1b Phase Offset Residual: GPS-CS486, GPS-CS017 (1 Day Update)

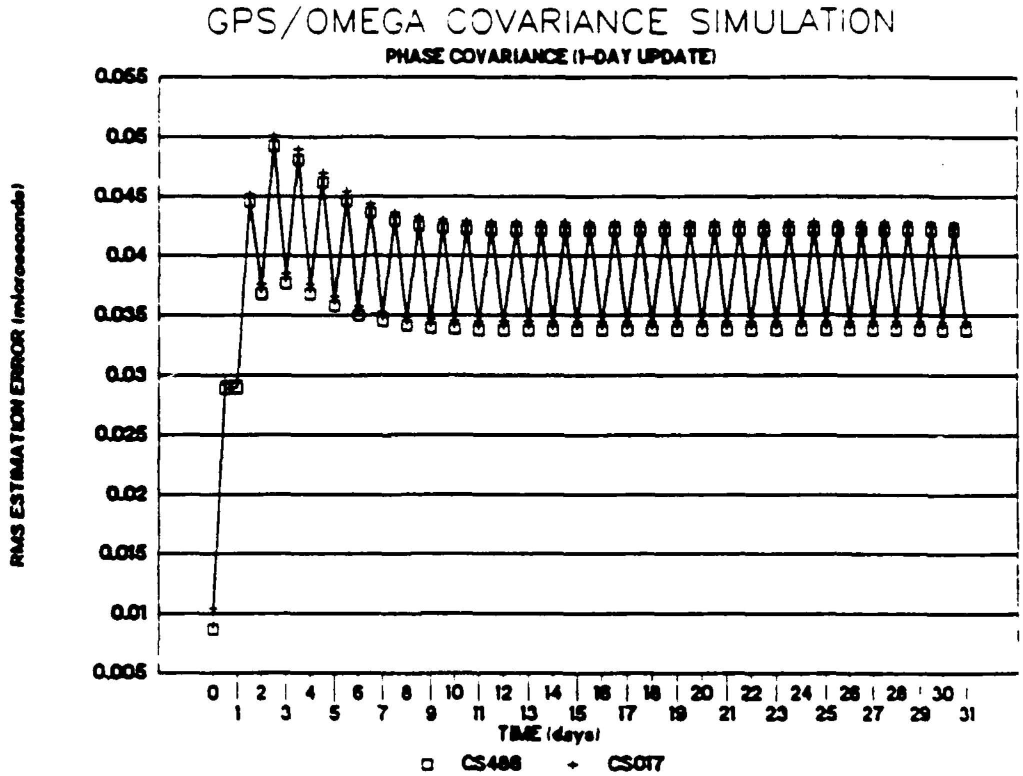


Figure 2.3-1c Phase Covariance (1 Day Update)

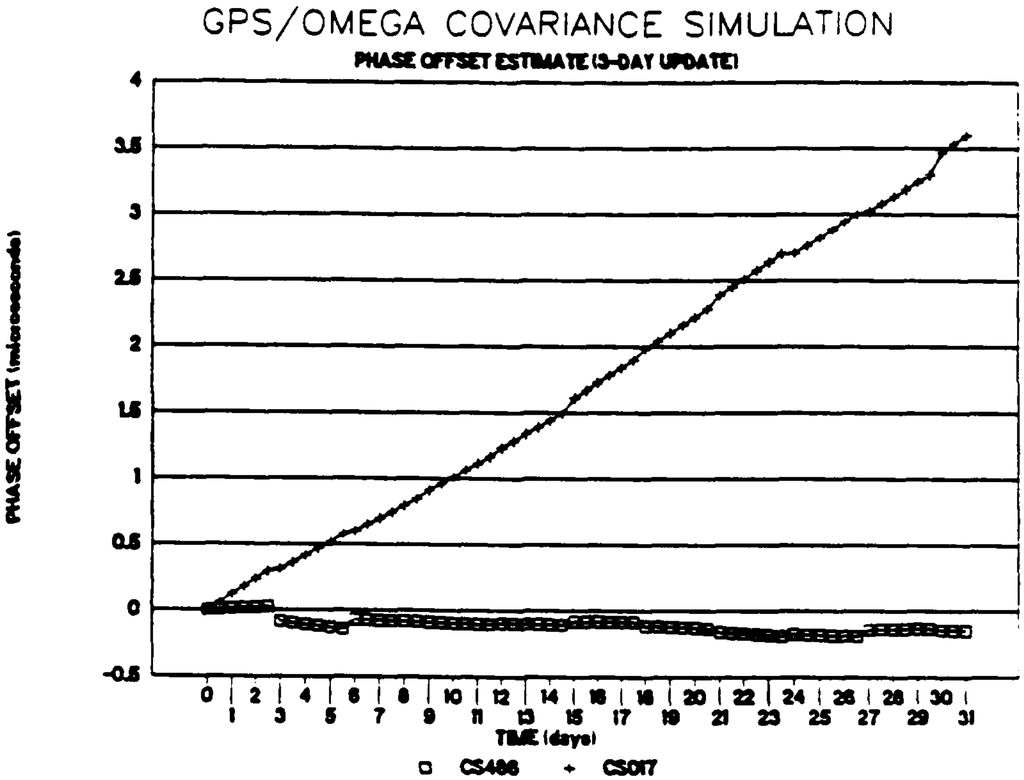


Figure 2.3-2a Phase Offset Estimate (3 Day Update)

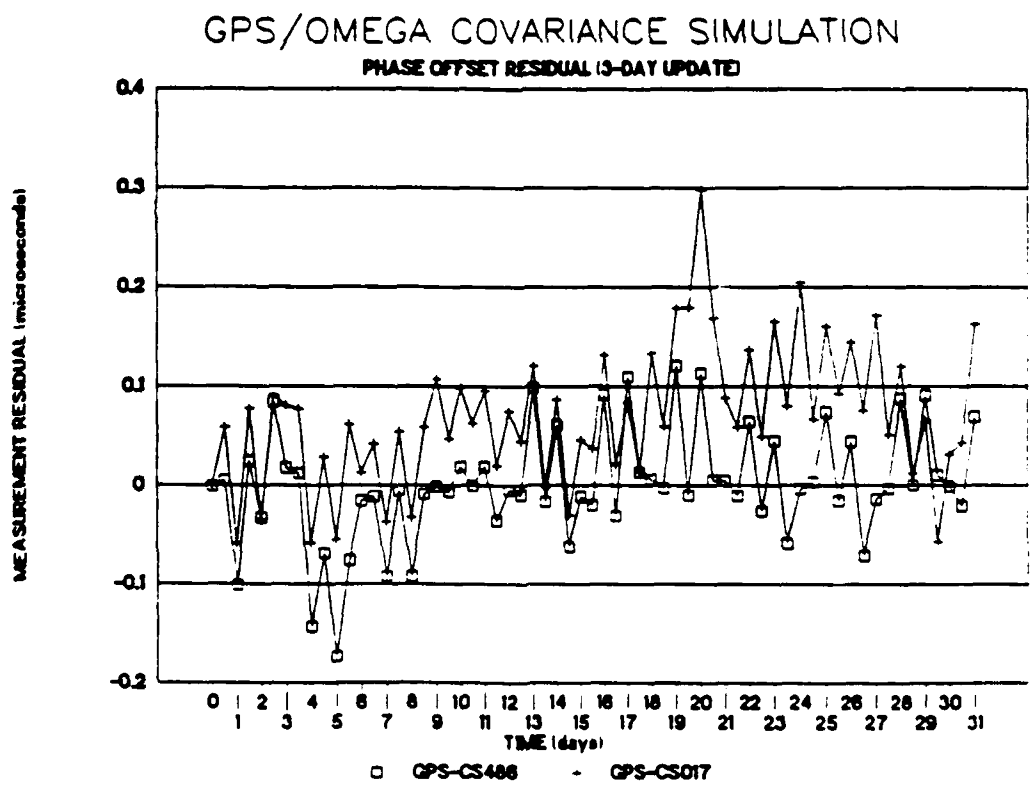


Figure 2.3-2b Phase Offset Residual: GPS-CS486, GPS-CS017 (3 Day Update)

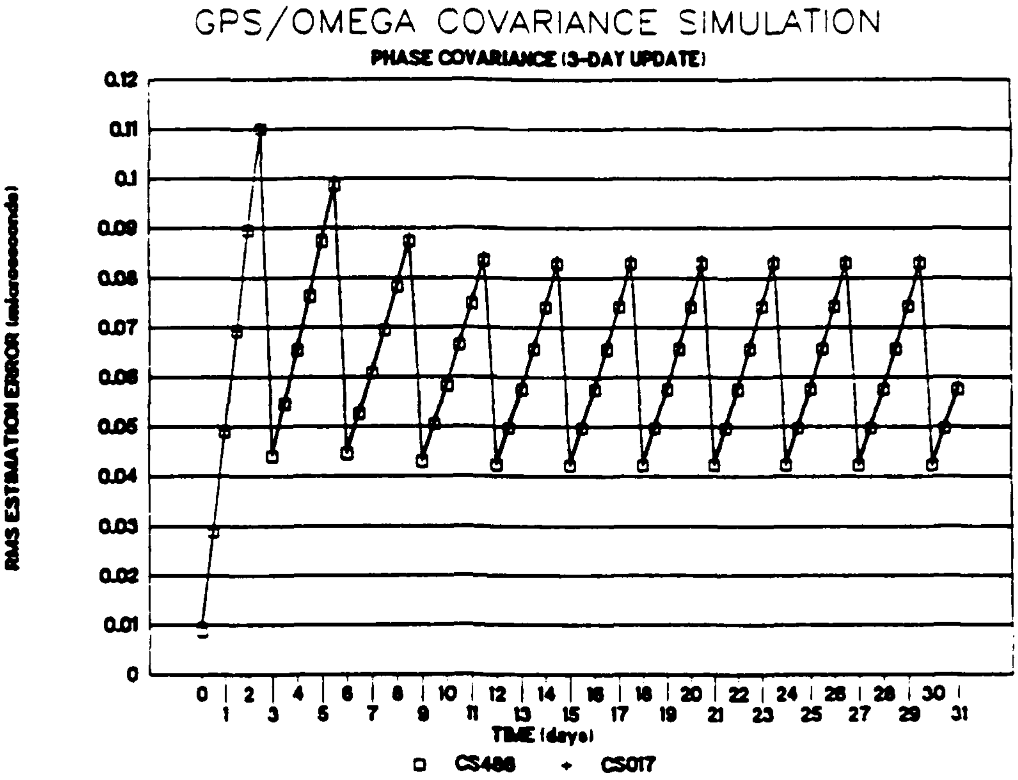


Figure 2.3-2c Phase Covariance (3 Day Update)

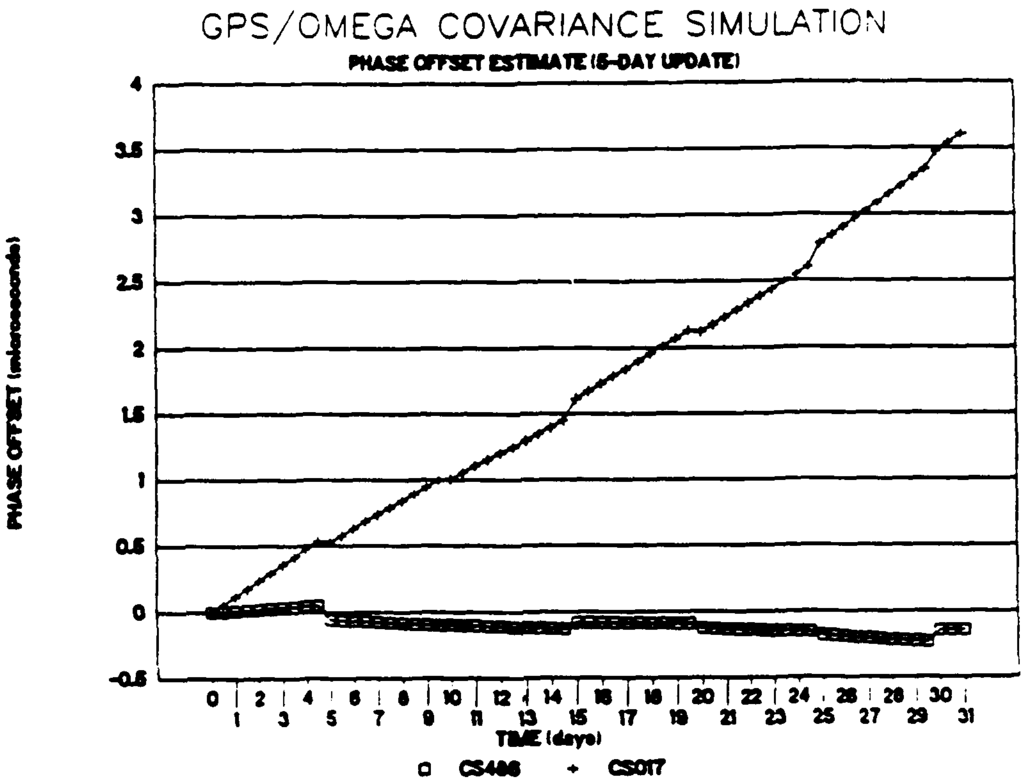


Figure 2.3-3a Phase Offset Estimate (5 Day Update)

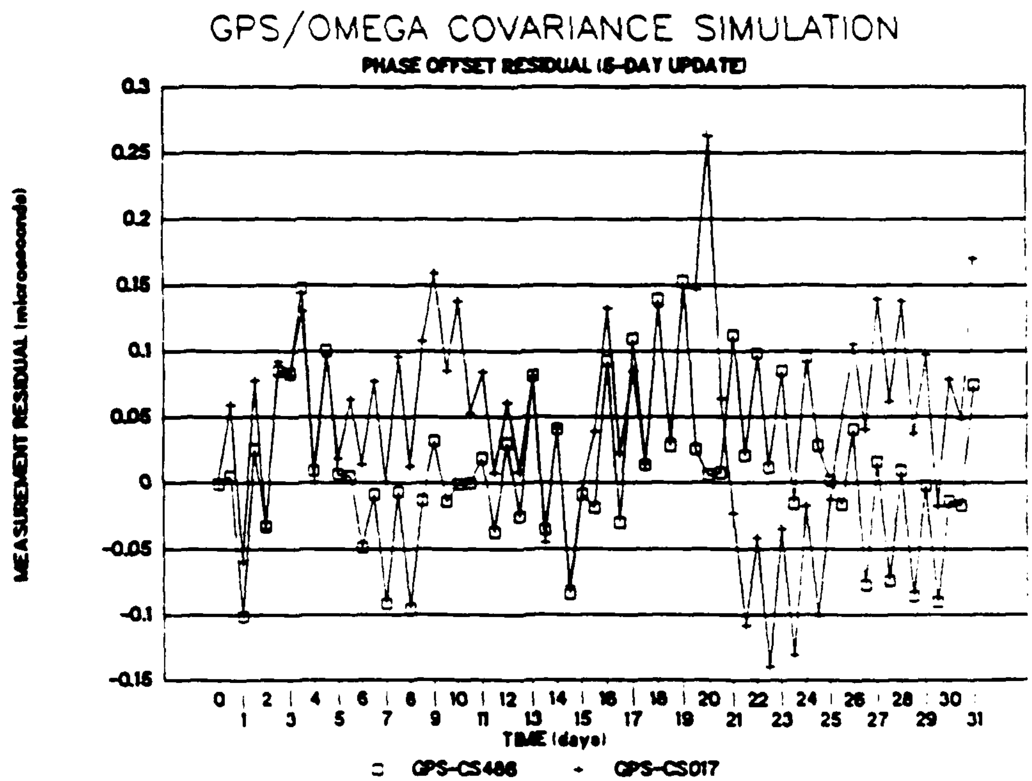


Figure 2.3-3b Phase Offset Residual: GPS-CS486, GPS-CS017 (5 Day Update)

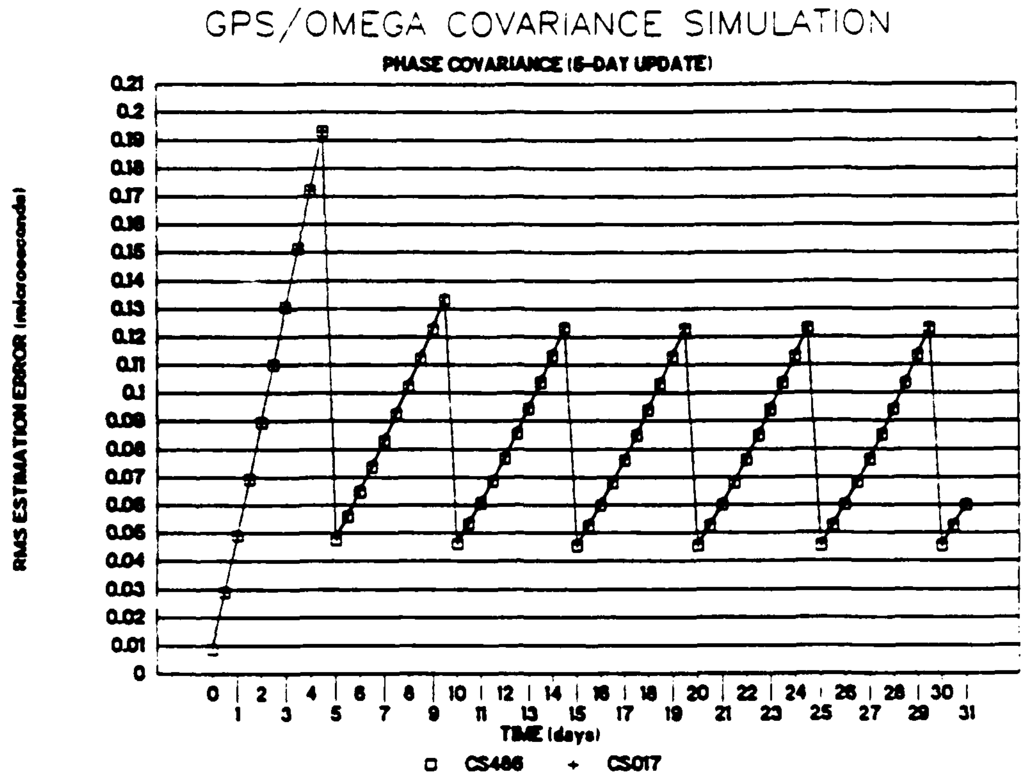


Figure 2.3-3c Phase Covariance (5 Day Update)

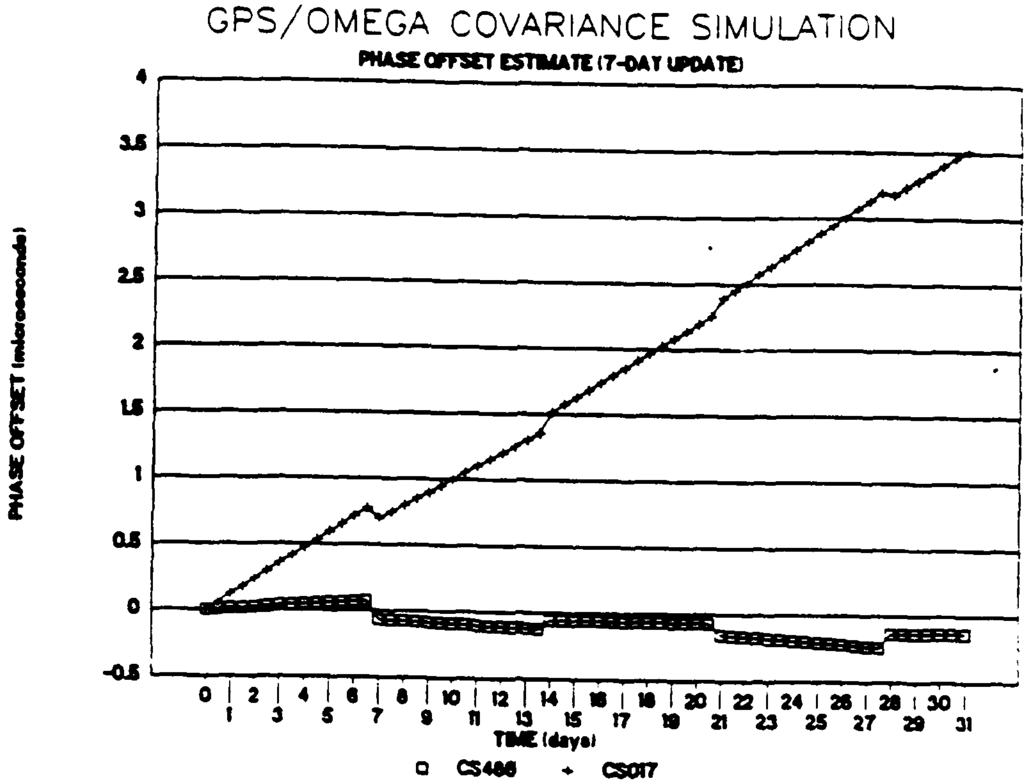


Figure 2.3-4a Phase Offset Estimate (7 Day Update)

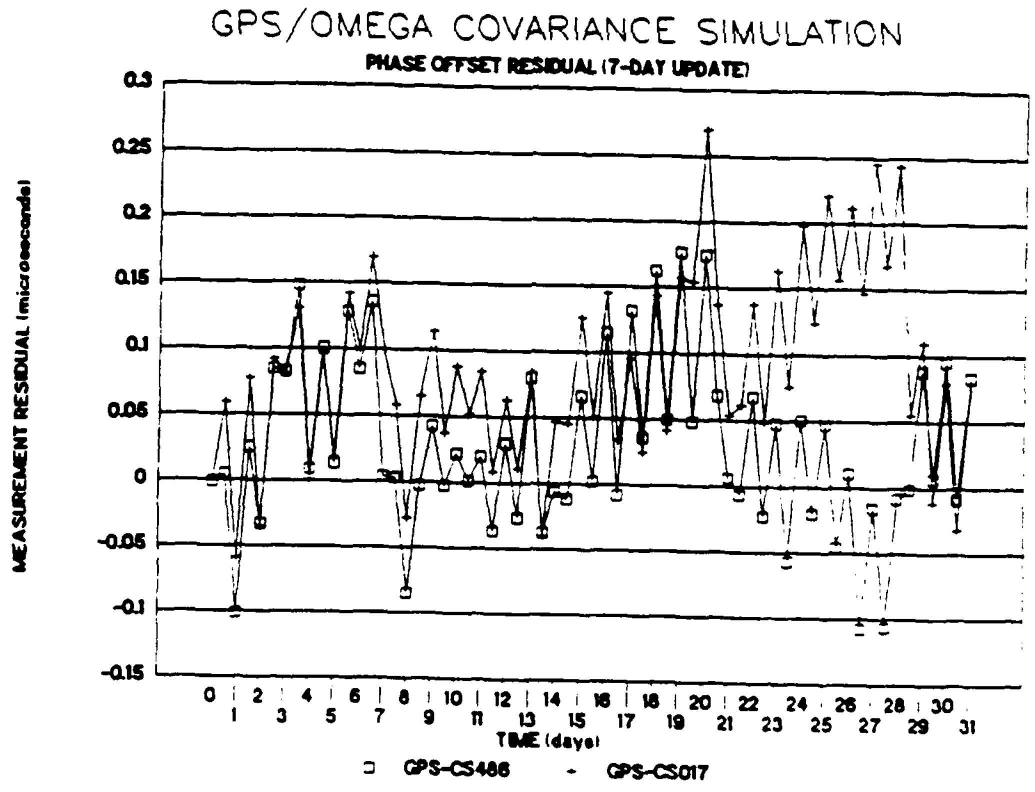


Figure 2.3-4b Phase Offset Residual: GPS-CS486, GPS-CS017 (7 Day Update)

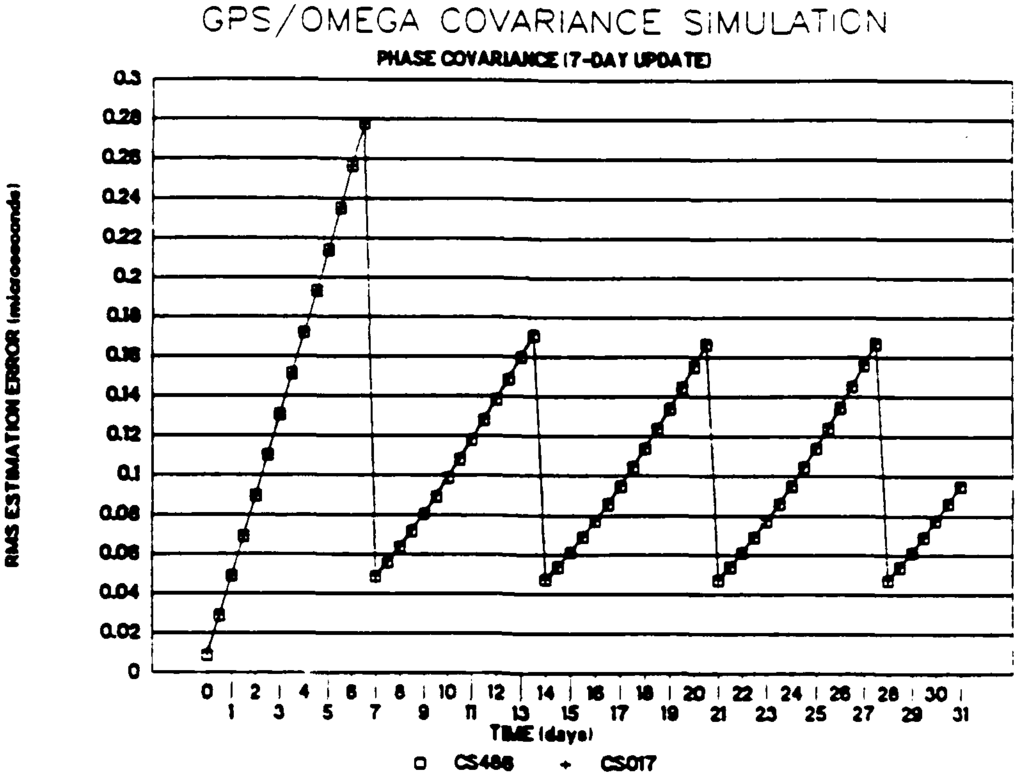


Figure 2.3-4c Phase Covariance (7 Day Update)

2.4 CONFIGURATION IV

Three types of plots were generated for this configuration. They are presented in the following order:

a) Phase Offset Estimate

b) Phase Offset Residual: GPS-CS486, GPS-CS017, GPS-CS124

c) Phase Covariance

This configuration was implemented by the following types of events: CLK1 and CLK2. Event "CLK1" identifies CS486-CS017 measurement and event "CLK2" identifies CS486-CS124 measurement. The remainder of this section contains plots as described above.

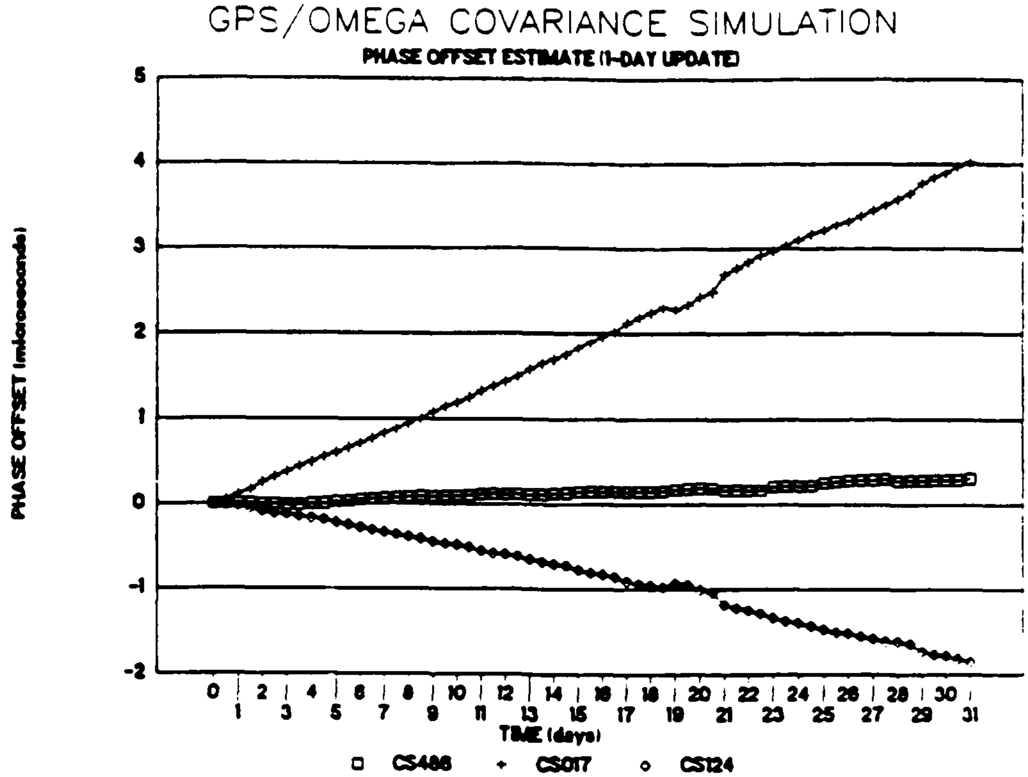


Figure 2.4-1a Phase Offset Estimate (1 Day Update)

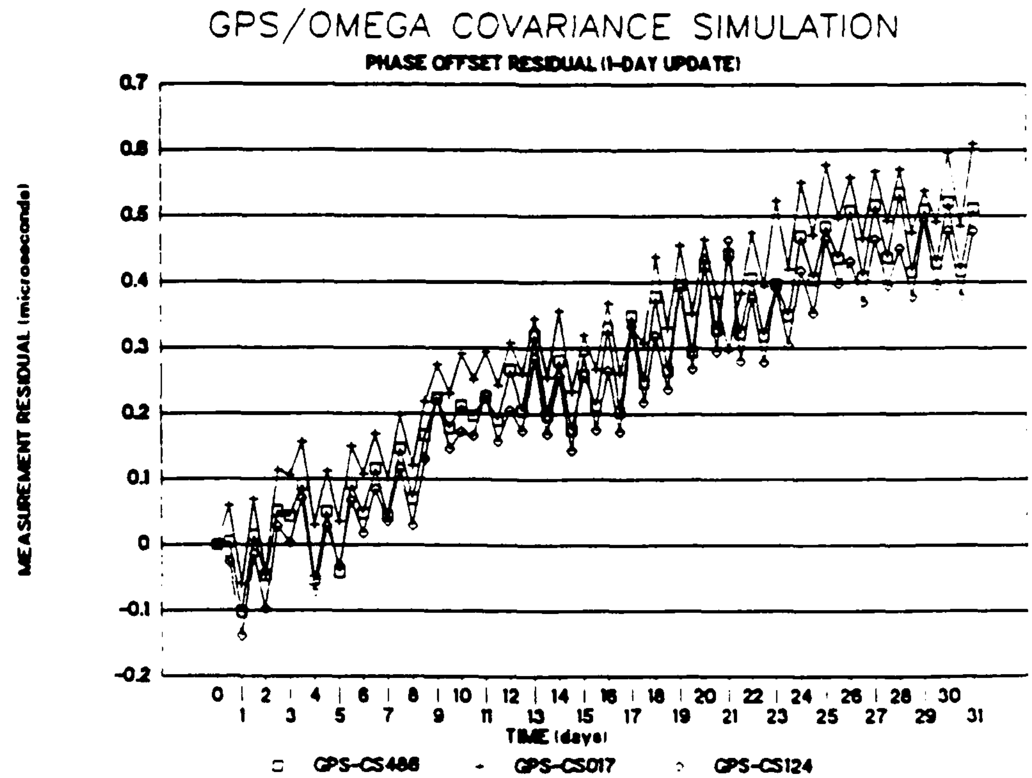


Figure 2.4-1b Phase Offset Residual: GPS-CS486, -CS017, -CS124 (1 Day Update)

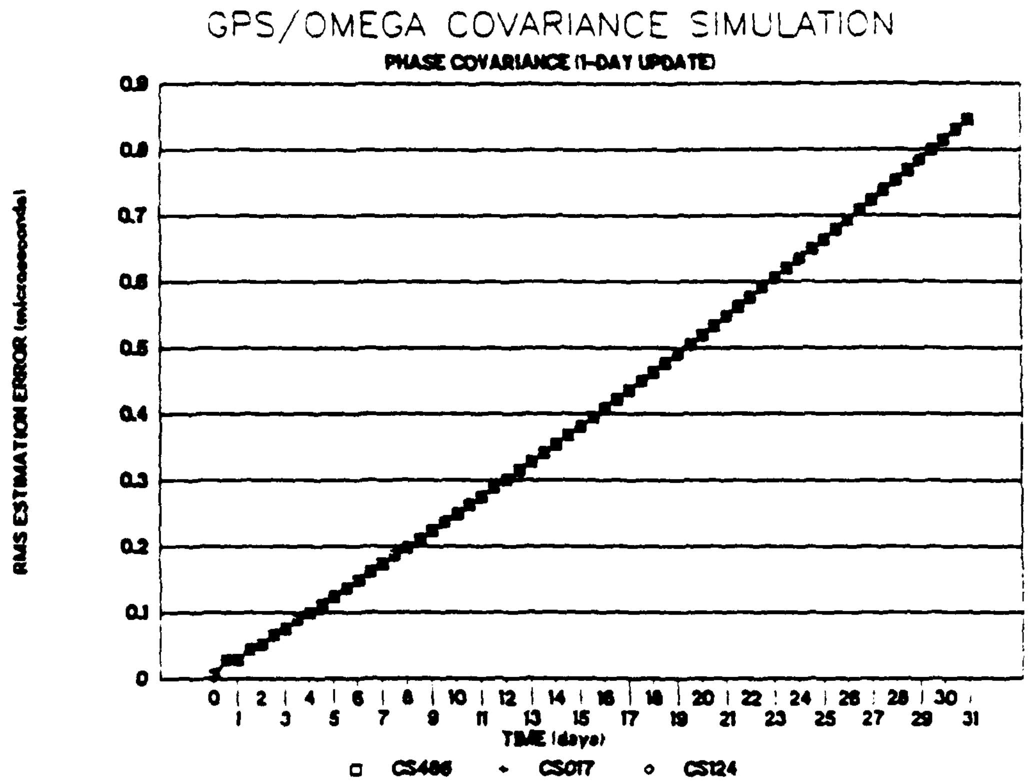


Figure 2.4-1c Phase Covariance (1 Day Update)

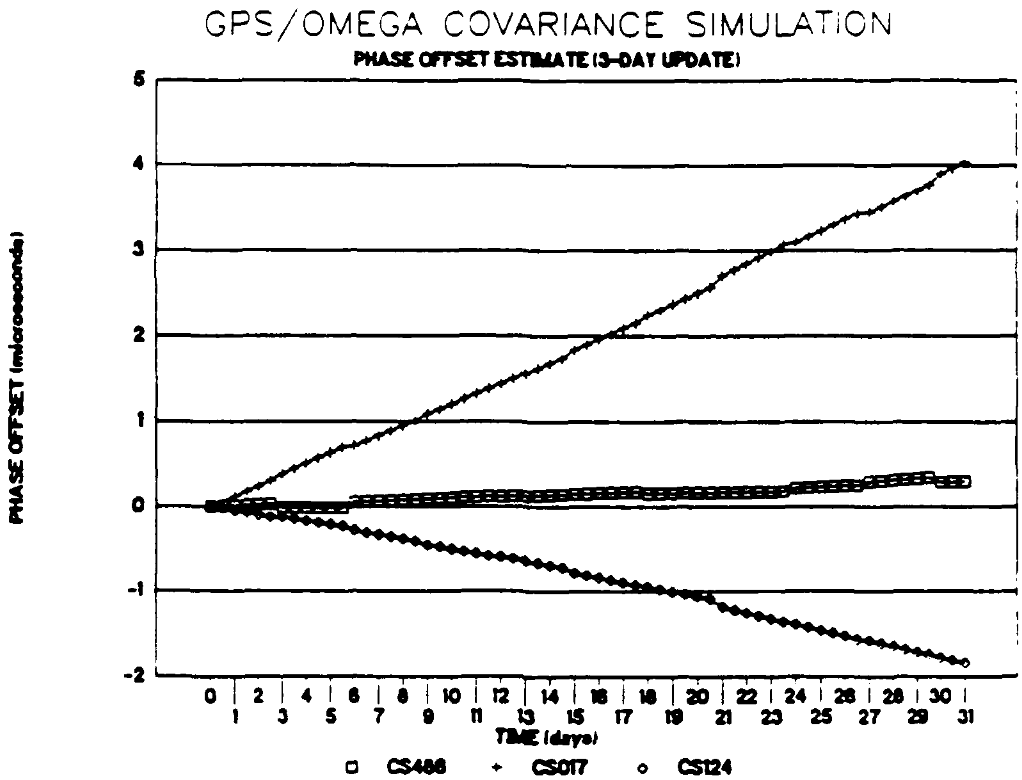


Figure 2.4-2a Phase Offset Estimate (3 Day Update)

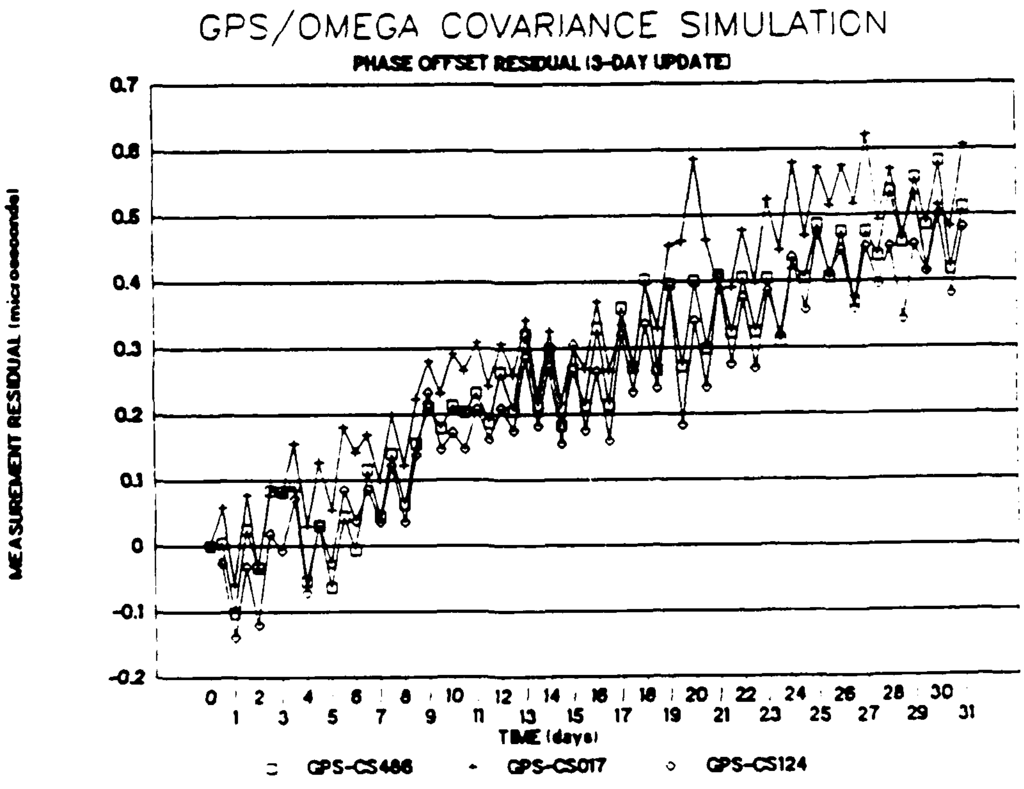


Figure 2.4-2b Phase Offset Residual: GPS-CS486, -CS017, -CS124 (3 Day Update)

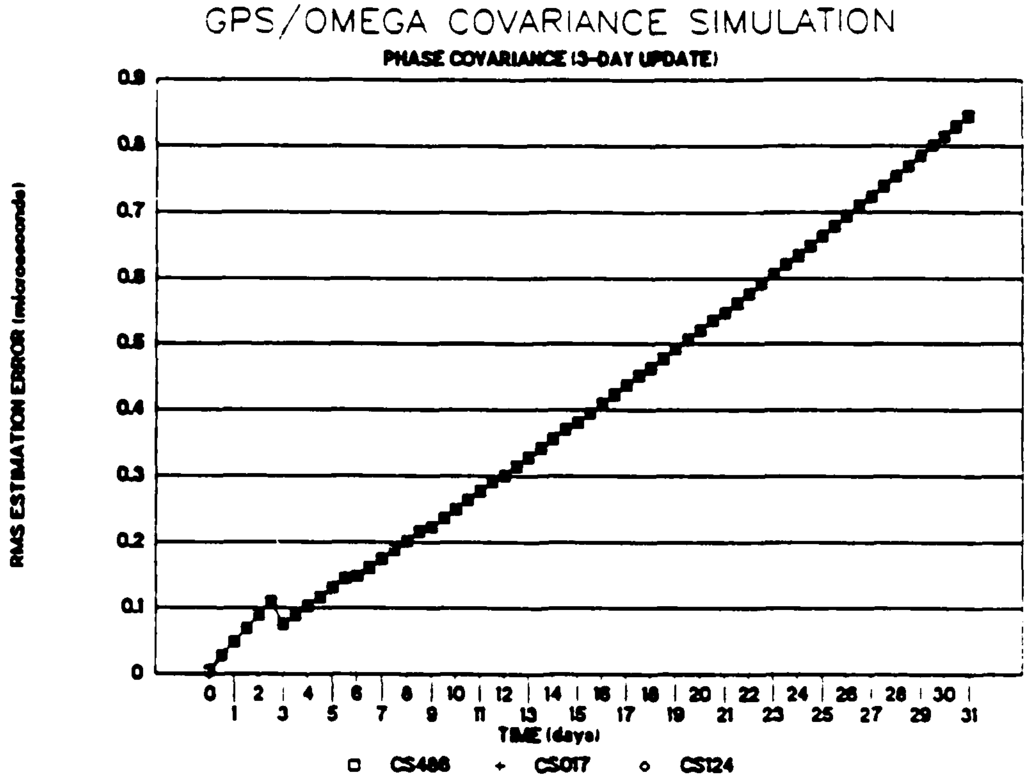


Figure 2.4-2c Phase Covariance (3 Day Update)

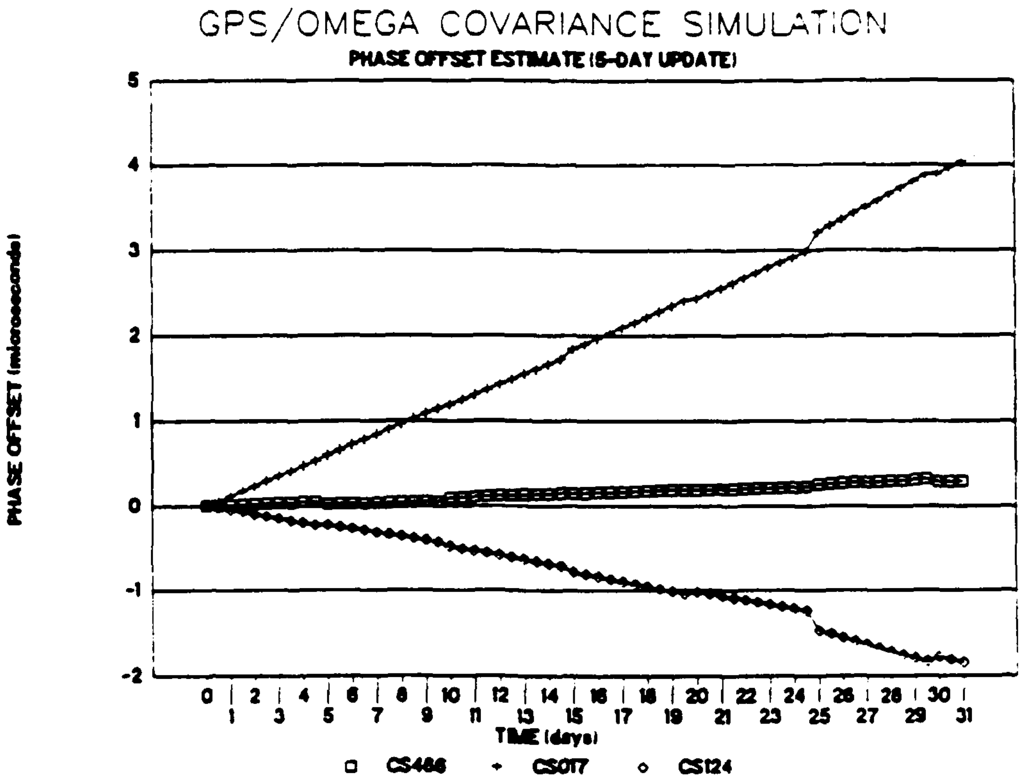


Figure 2.4-3a Phase Offset Estimate (5 Day Update)

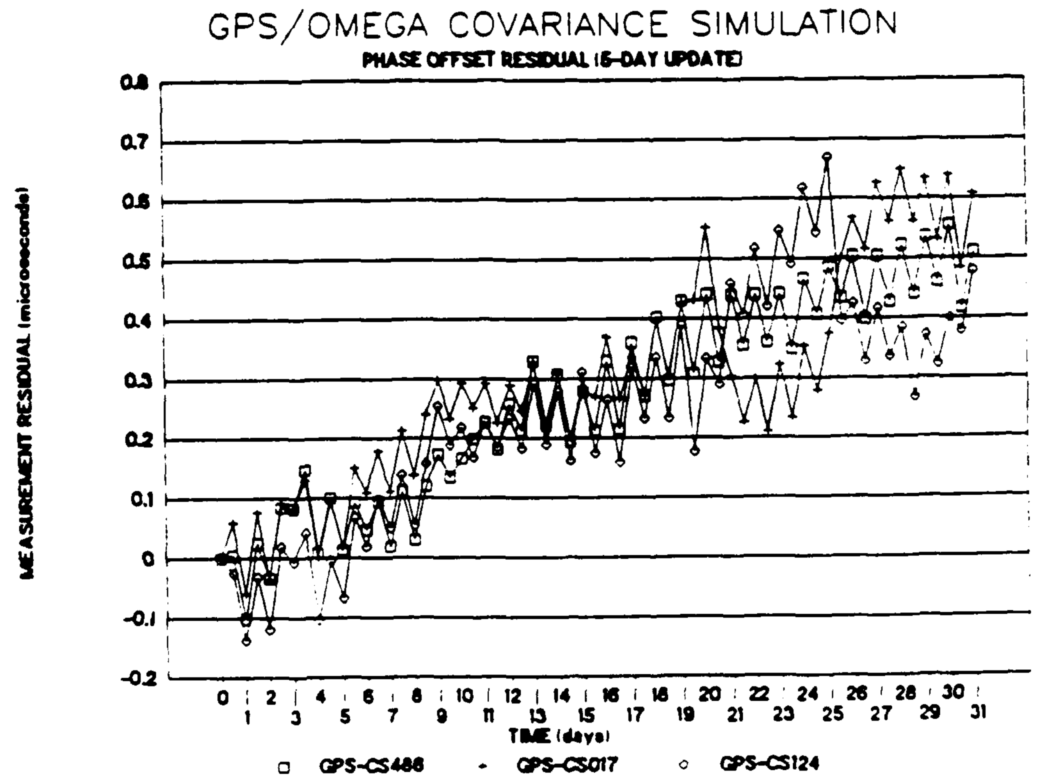


Figure 2.4-3b Phase Offset Residual: GPS-CS486, -CS017, -CS124 (5 Day Update)

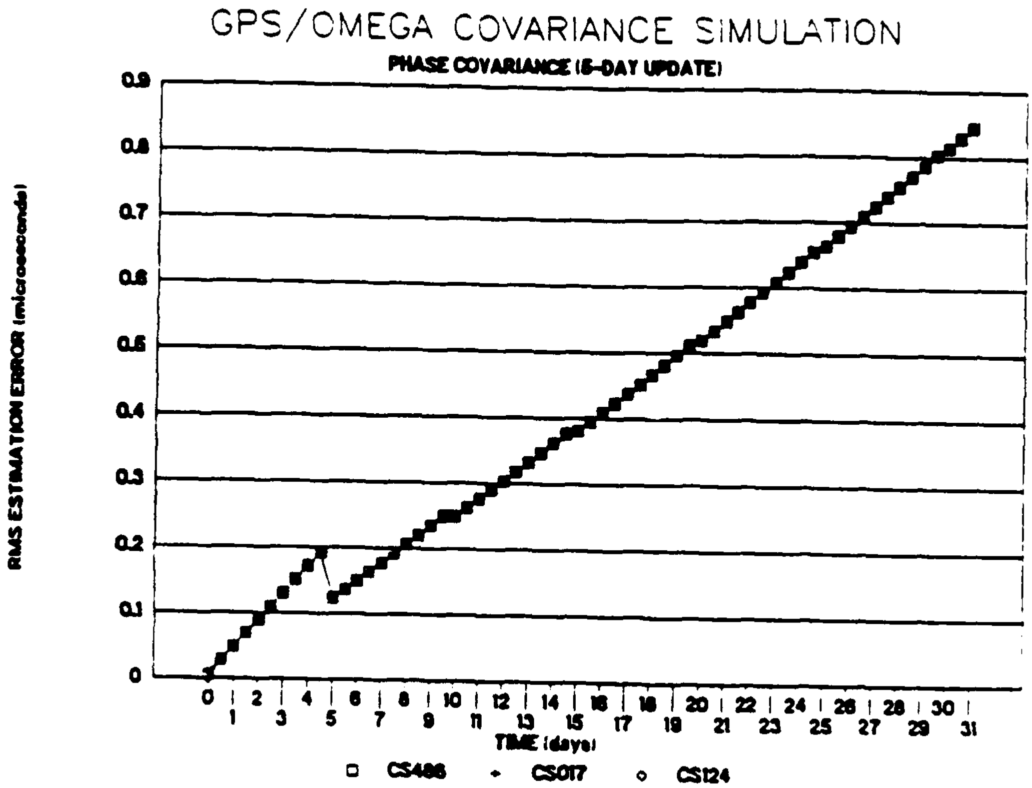


Figure 2.4-3c Phase Covariance (5 Day Update)

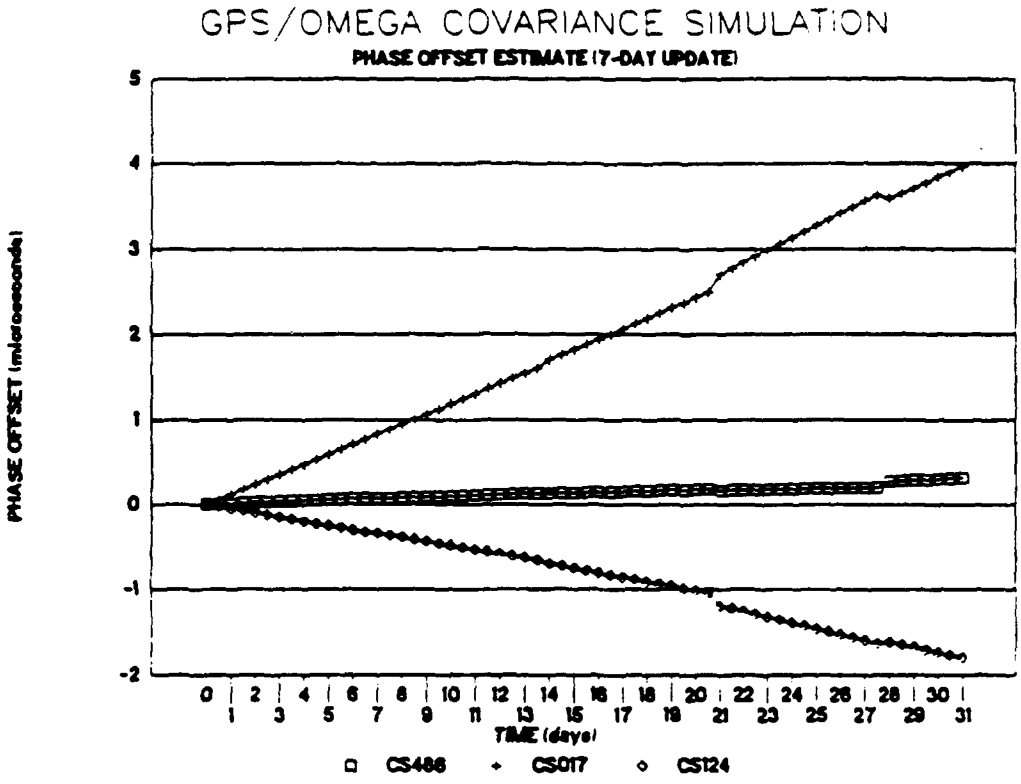


Figure 2.4-4a Phase Offset Estimate (7 Day Update)

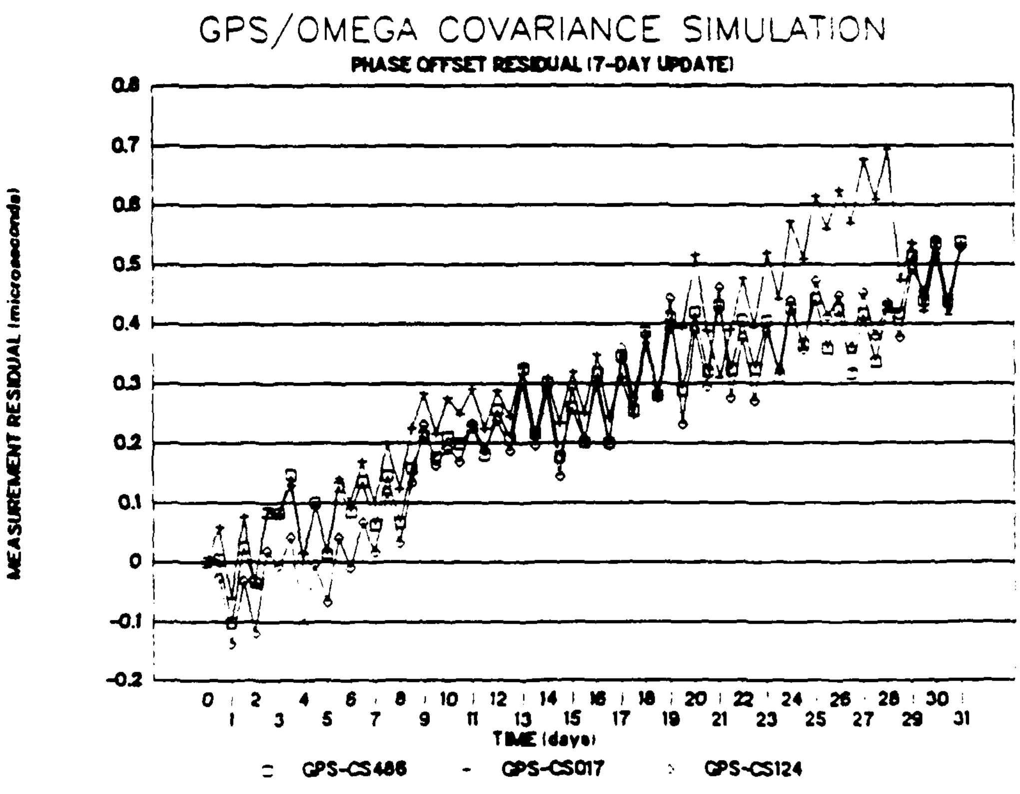


Figure 2.4-4b Phase Offset Residual: GPS-CS486, -CS017, -CS124 (7 Day Update)

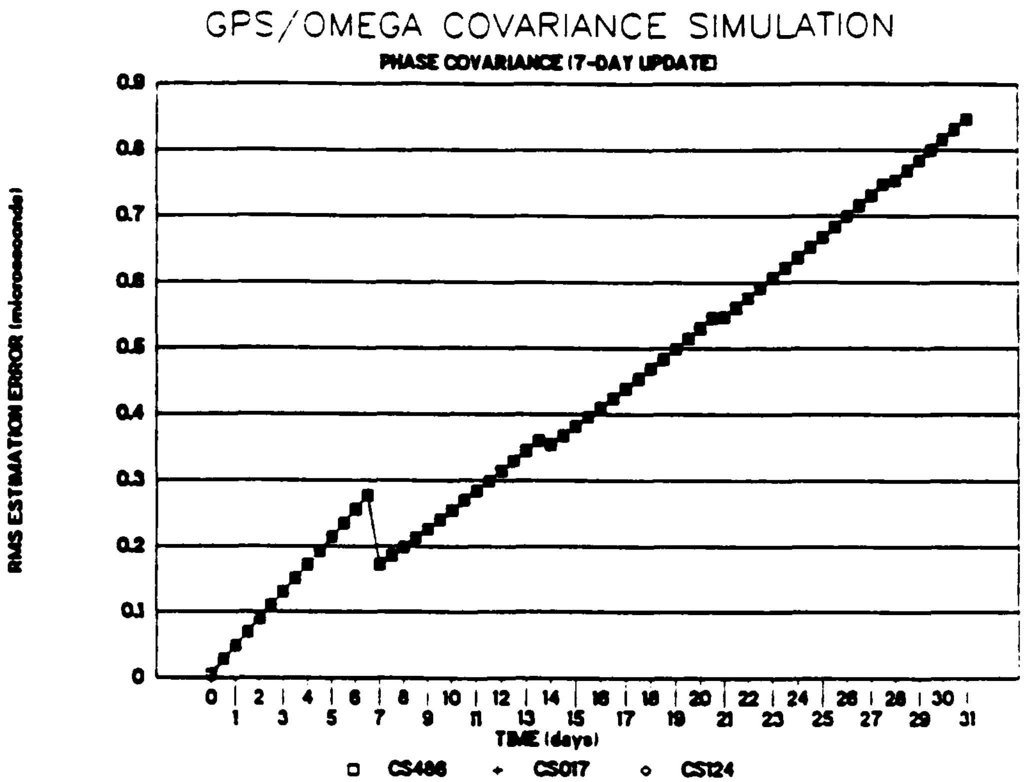


Figure 2.4-4c Phase Covariance (7 Day Update)

2.5 CONFIGURATION V

Three types of plots were generated for this configuration. They are presented in the following order:

a) Phase Offset Estimate

b) Phase Offset Residual: GPS-CS486, GPS-CS017

c) Phase Covariance

This configuration was implemented by the following event: CLK1. This event identifies CS486-CS017 measurement. The remainder of this section contains plots as described above.

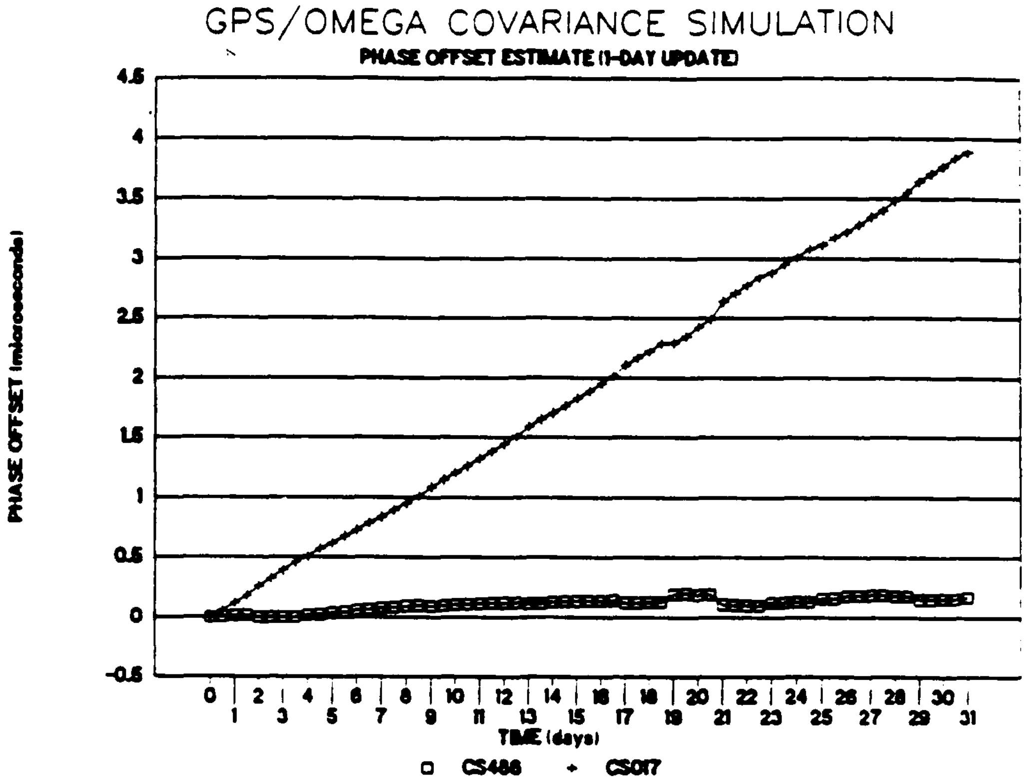


Figure 2.5-1a Phase Offset Estimate (1 Day Update)

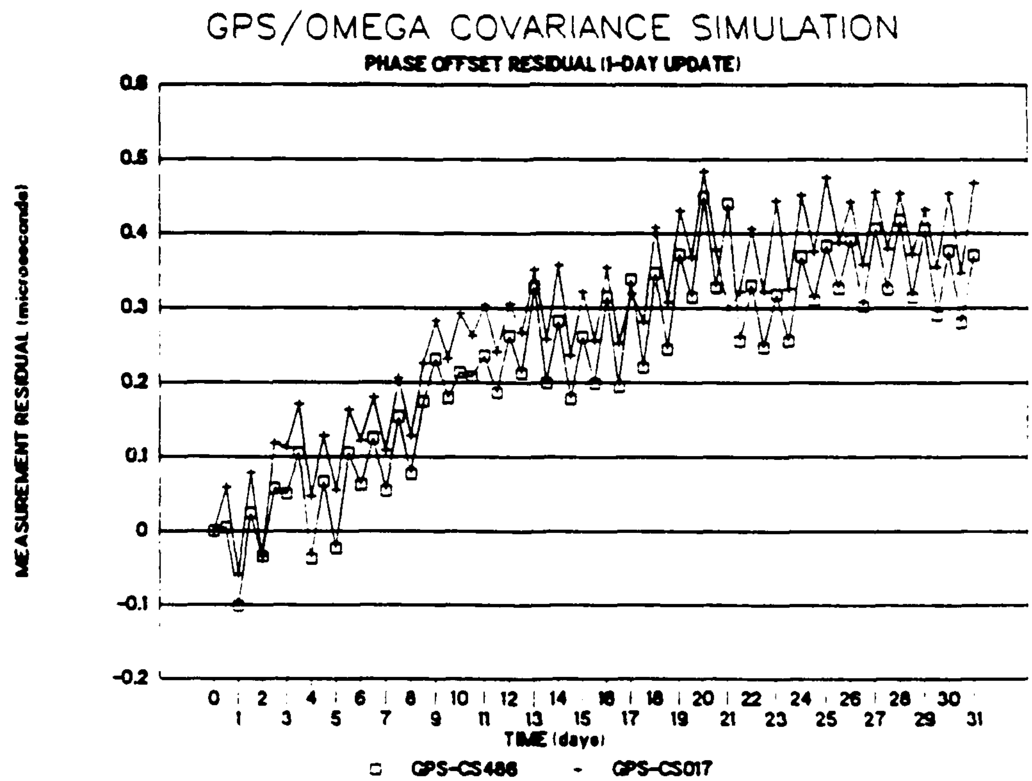


Figure 2.5-1b Phase Offset Residual: GPS-CS486, GPS-CS017 (1 Day Update)

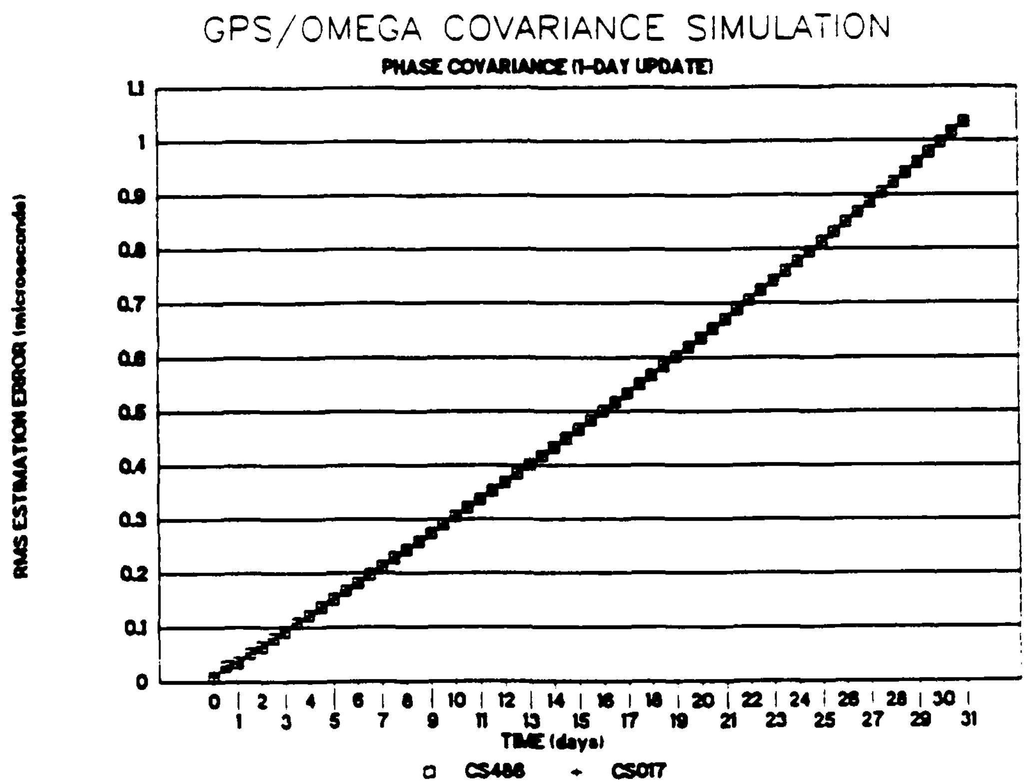


Figure 2.5-1c Phase Covariance (1 Day Update)

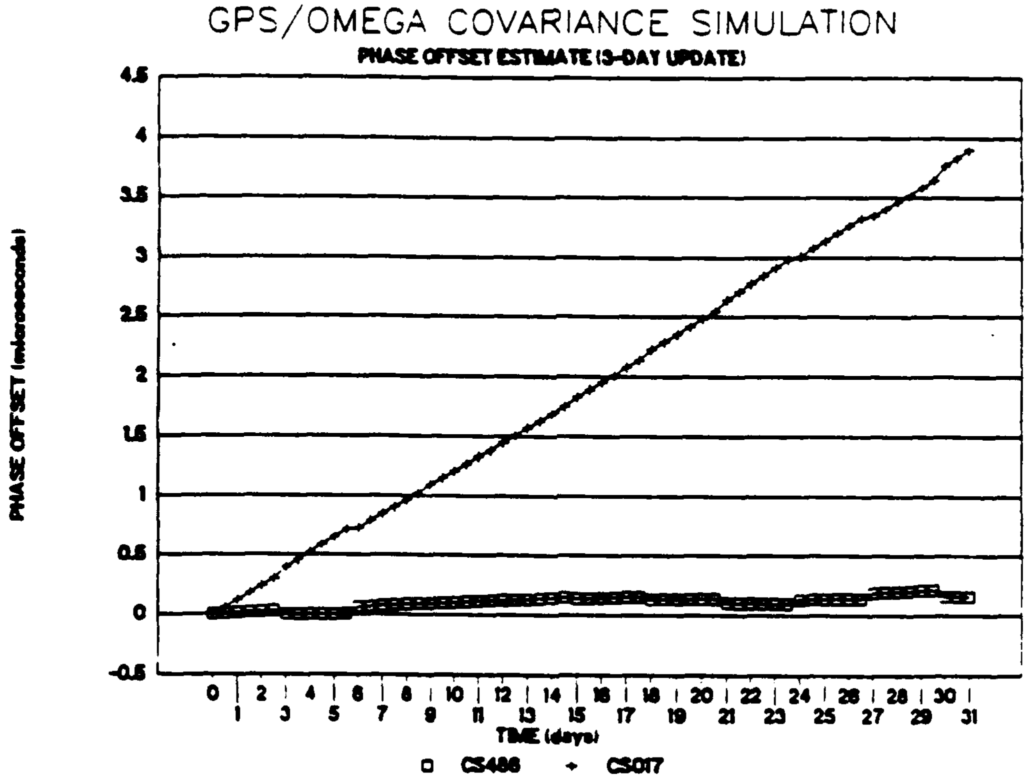


Figure 2.5-2a Phase Offset Estimate (3 Day Update)

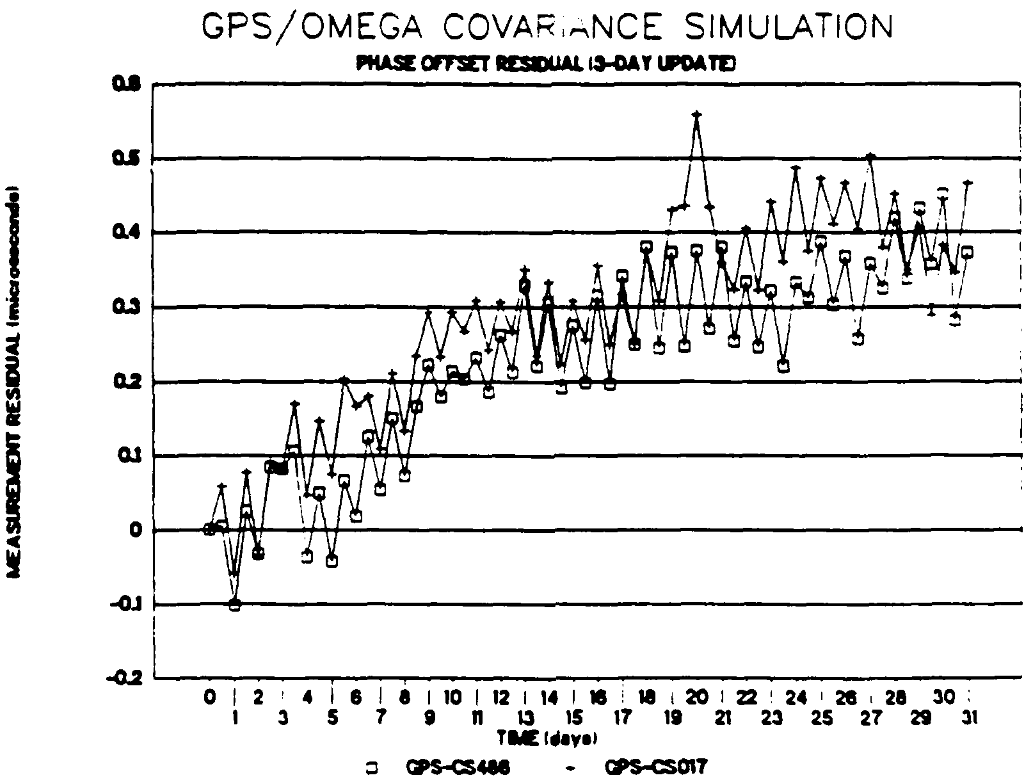


Figure 2.5-2b Phase Offset Residual: GPS-CS486, GPS-CS017 (3 Day Update)

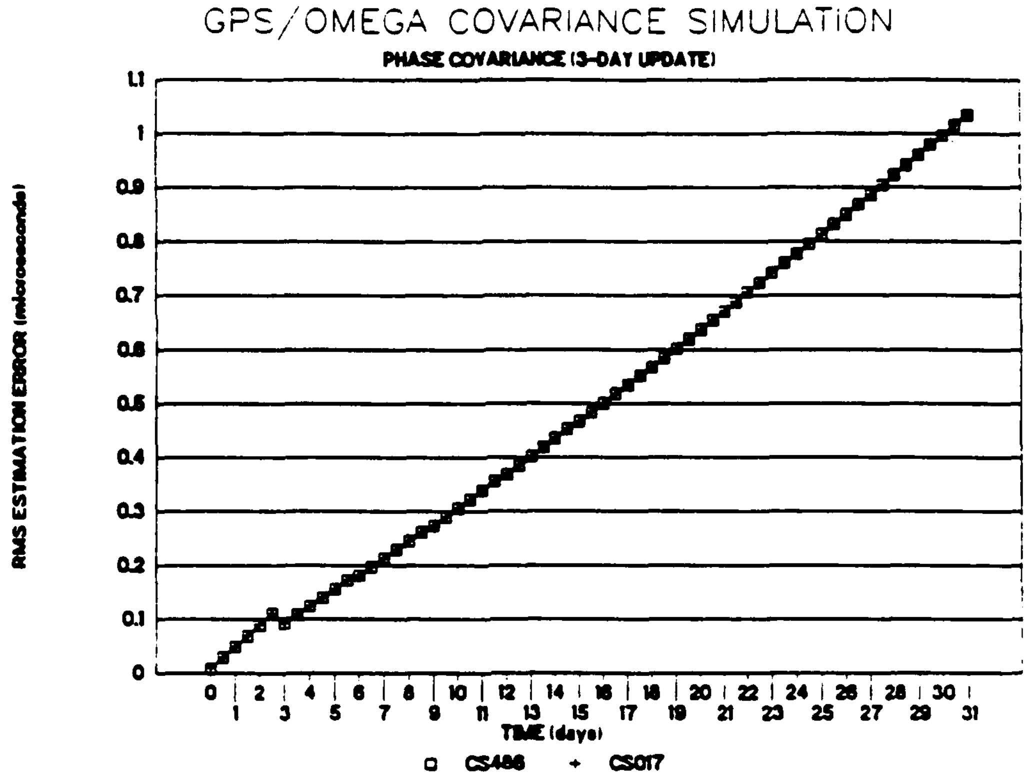


Figure 2.5-2c Phase Covariance (3 Day Update)

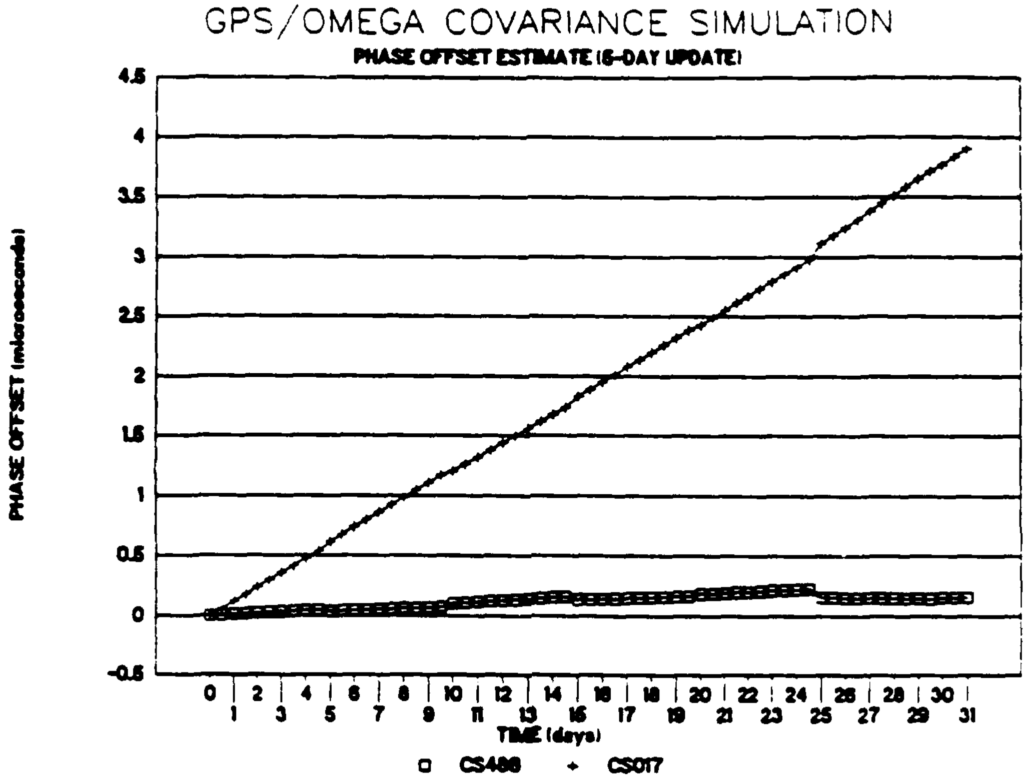


Figure 2.5-3a Phase Offset Estimate (5 Day Update)

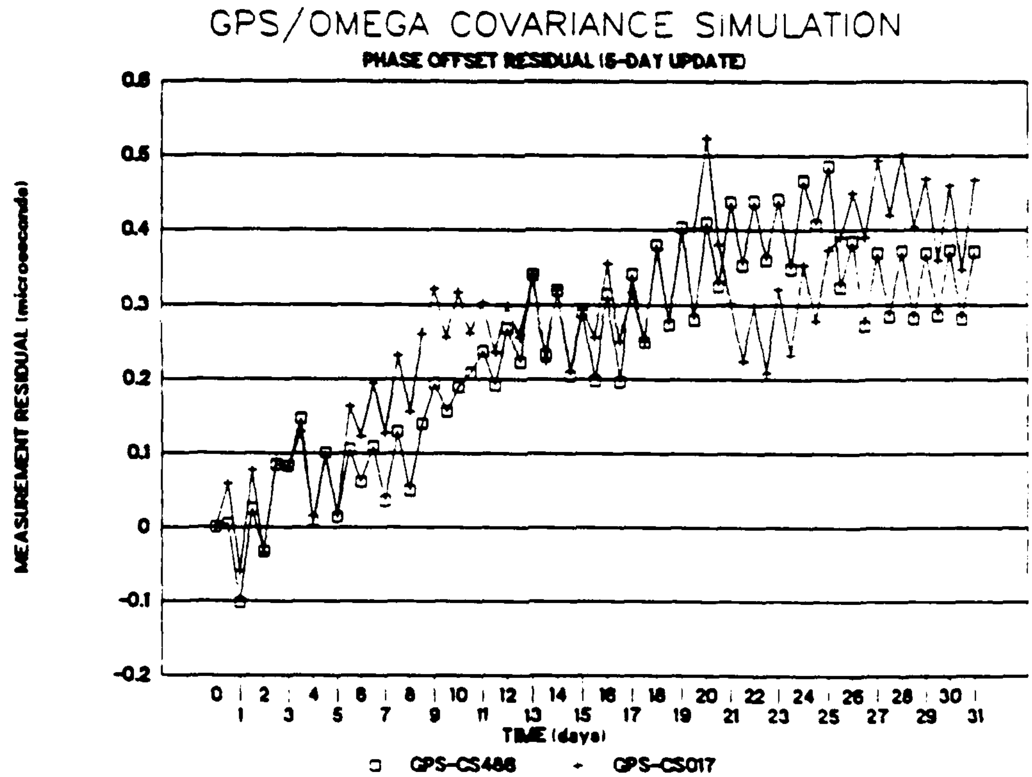


Figure 2.5-3b Phase Offset Residual: GPS-CS486, GPS-CS017 (5 Day Update)

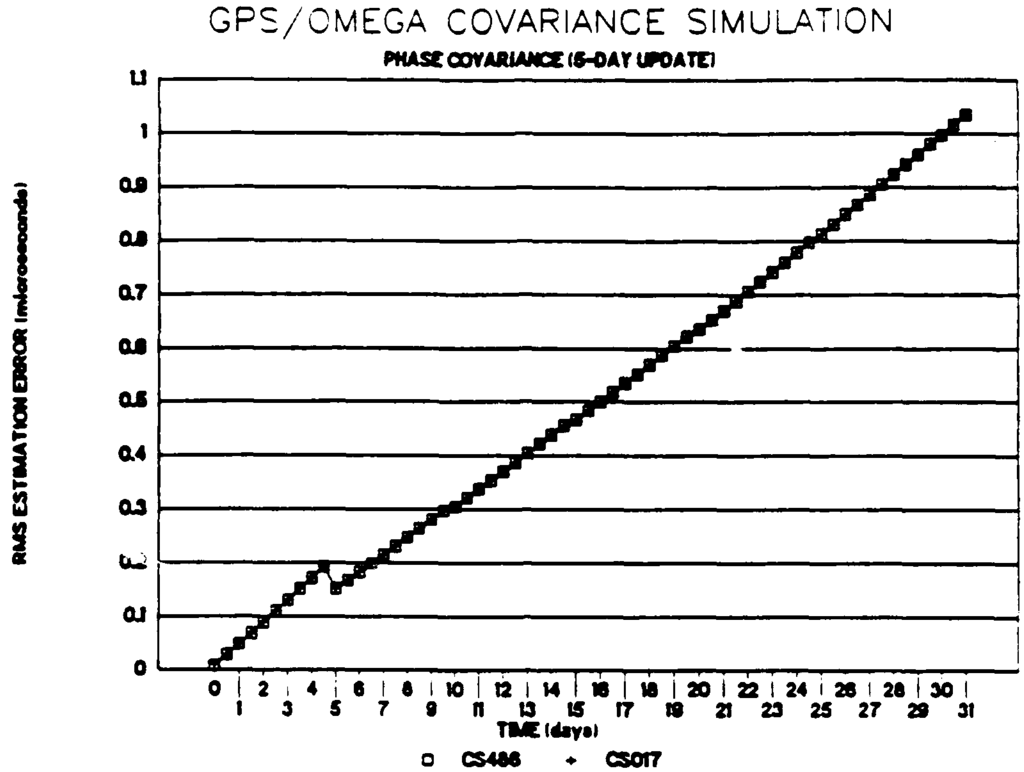


Figure 2.5-3c Phase Covariance (5 Day Update)

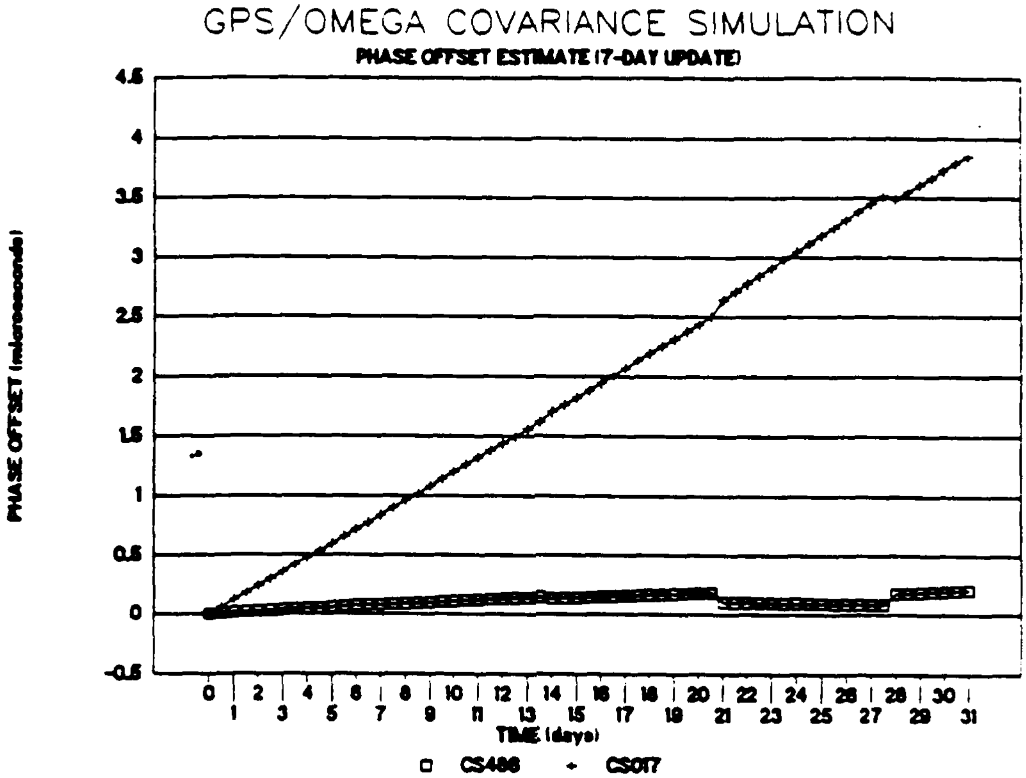


Figure 2.5-4a Phase Offset Estimate (7 Day Update)

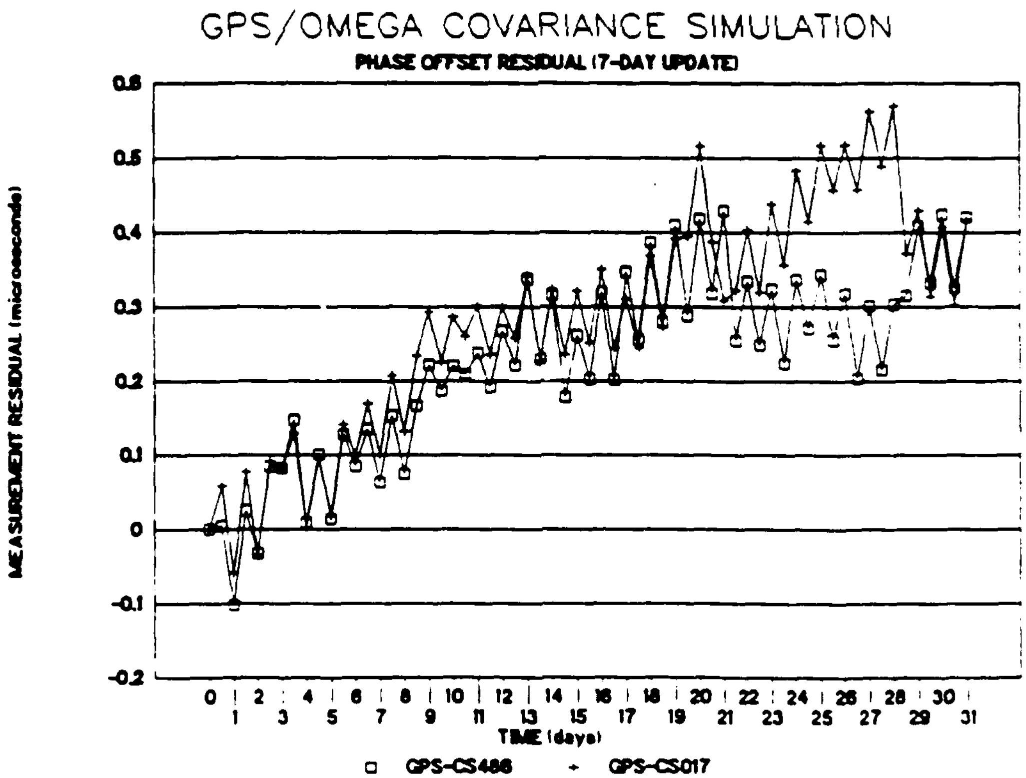


Figure 2.5-4b Phase Offset Residual: GPS-CS486, GPS-CS017 (7 Day Update)

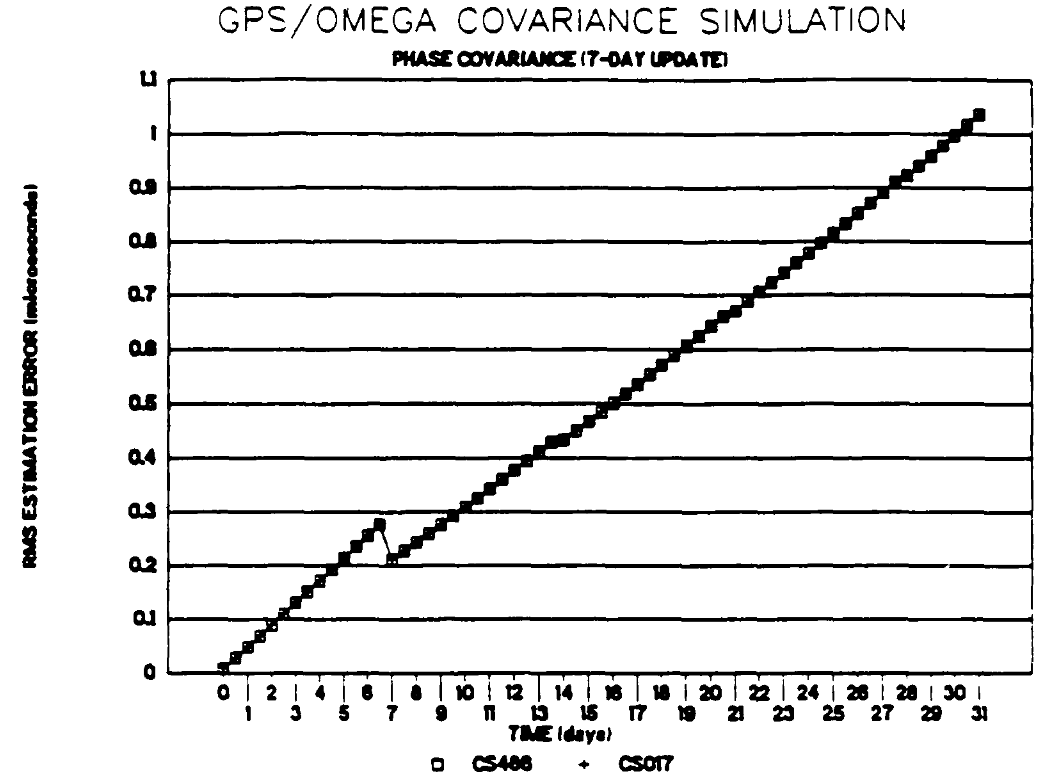


Figure 2.5-4c Phase Covariance (7 Day Update)

3. HAWAII

Table 3-1 depicts five CSP configurations that were used to process RDAS timing data from Omega Station.

Table 3-1
CSP TEST CONFIGURATION
(Hawaii Station)

CONFIGURATION NO.	GPS TIME TRANSFER	ON-LINE CESIUM (CS529)	PRIMARY CESIUM (CS554)	SECONDARY CESIUM (CS349)
I	On	On	On	On
II	On	On	On	On
III	On	On	On	Off
IV	Off	On	On	On
V	Off	On	On	Off

3.1 CONFIGURATION I

Seven types of plots were generted for this configuration. They are presented in the following order:

a) Phase Offset Estimate

b) Frequency Offset Estimate

c) Phase Offset Residual: GPS-CS529, GPS-CS554, GPS-CS349

d) Phase Covariance

e) Frequency Covariance

This configuration was implemented by the following types of events: GPS1, GPS2 and GPS3. Event "GPS1" identifies GPS-CS529 measurement; event "GPS2" identifies GPS-CS554 measurement and event "GPS3" identifies GPS-CS349 measurement. The remainder of this section contains plots as described above.

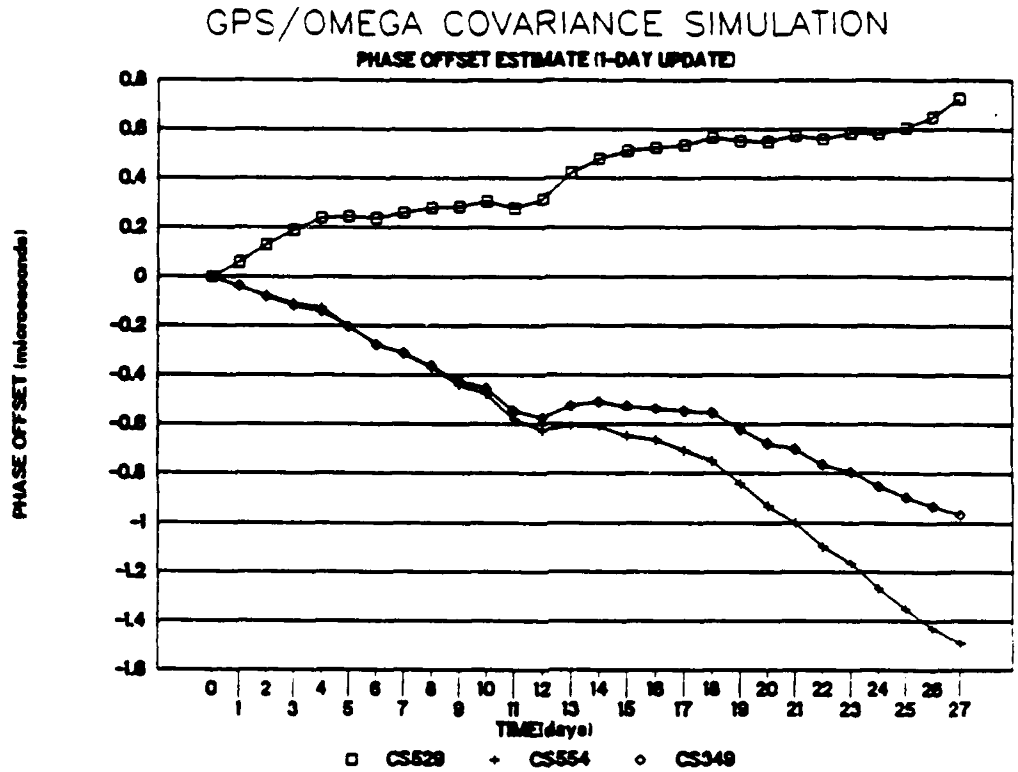


Figure 3.1-1a Phase Offset Estimate (1 Day Update)

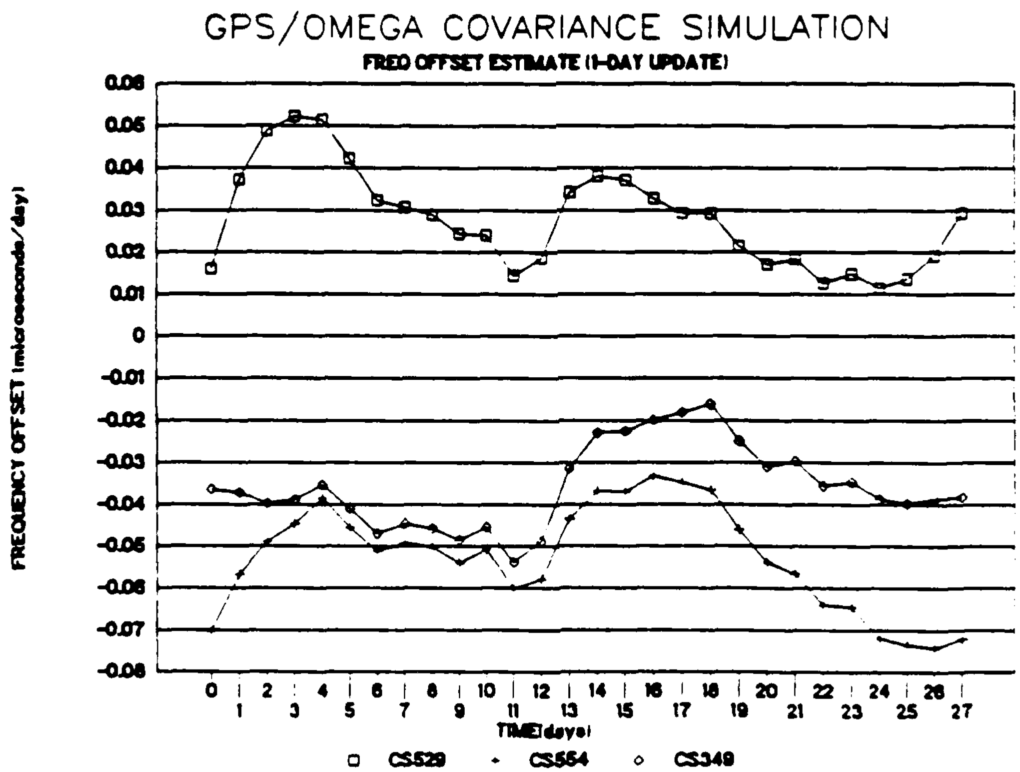


Figure 3.1-1b Frequency Offset Estimate (1 Day Update)

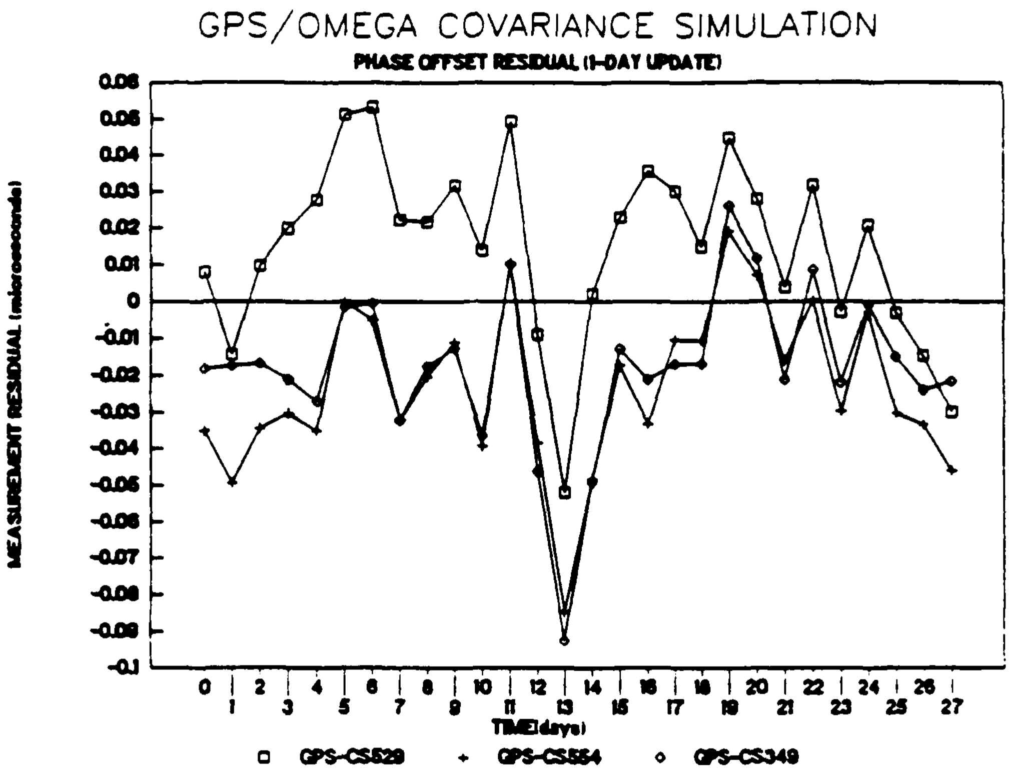


Figure 3.1-1c Phase Offset Residual: GPS-CS529, GPS-CS554, GPS-CS349 (1 Day Update)

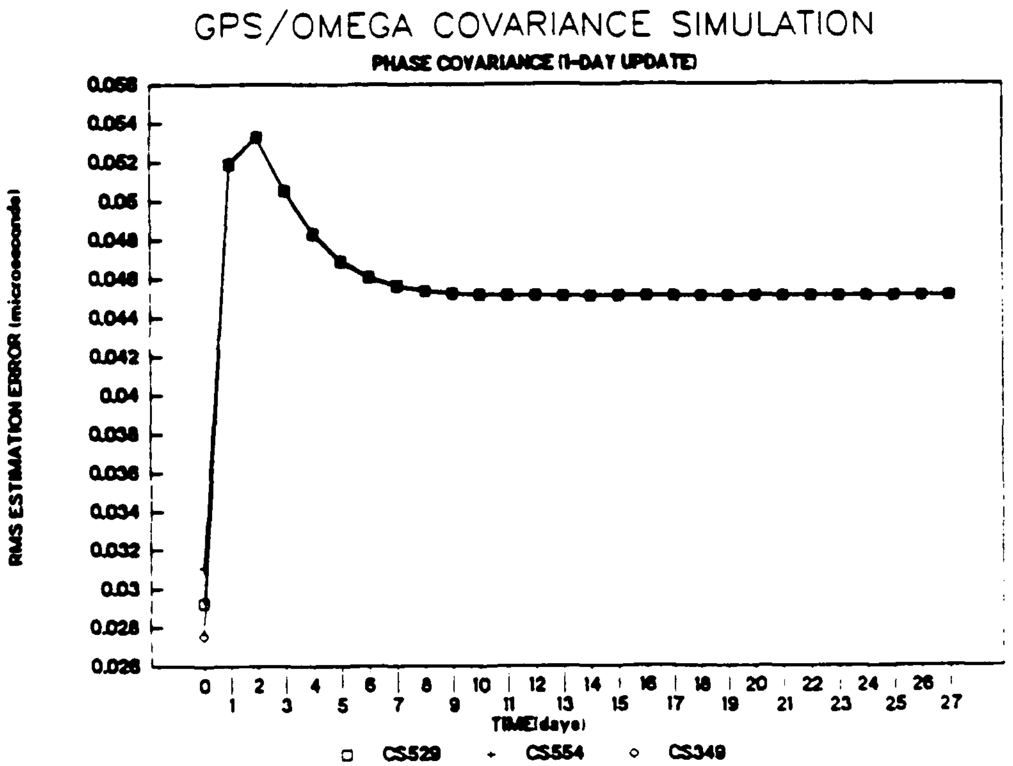


Figure 3.1-1d Phase Covariance (1 Day Update)

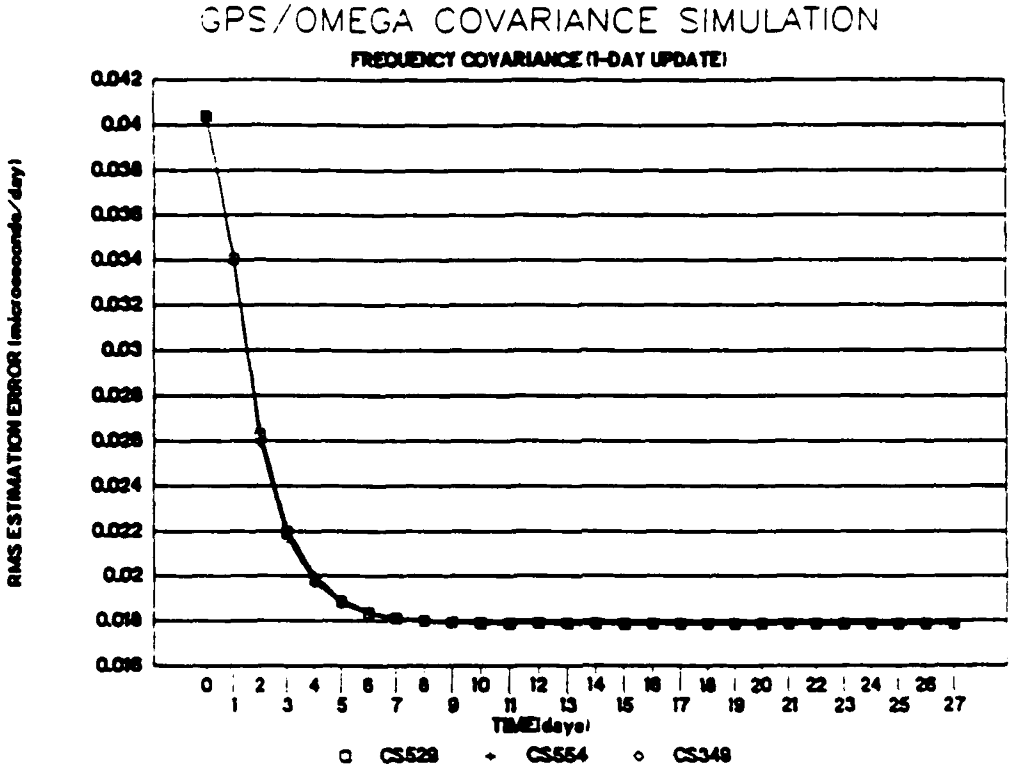


Figure 3.1-1e Frequency Covariance (1 Day Update)

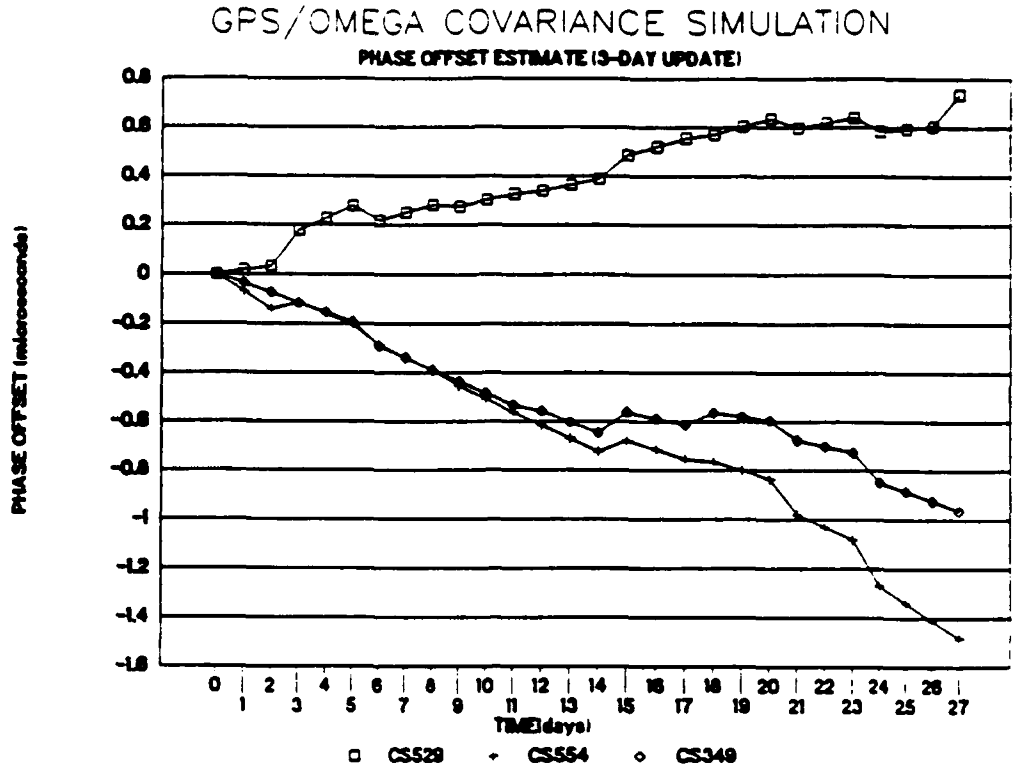


Figure 3.1-2a Phase Offset Estimate (3 Day Update)

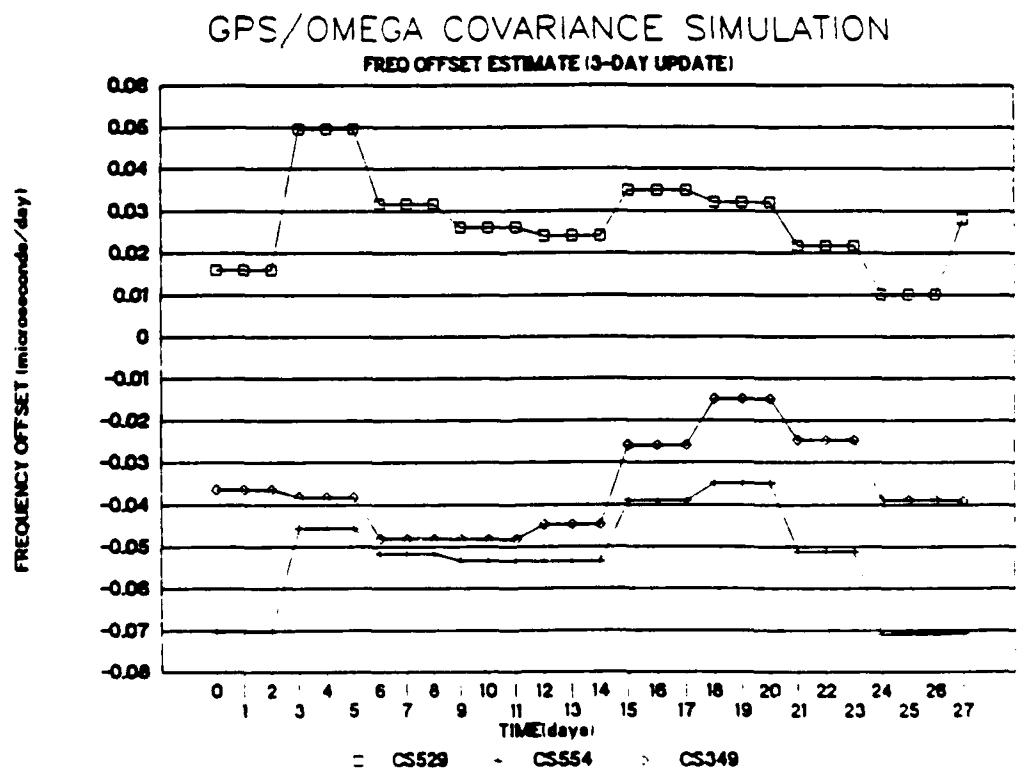


Figure 3.1-2b Frequency Offset Estimate (3 Day Update)

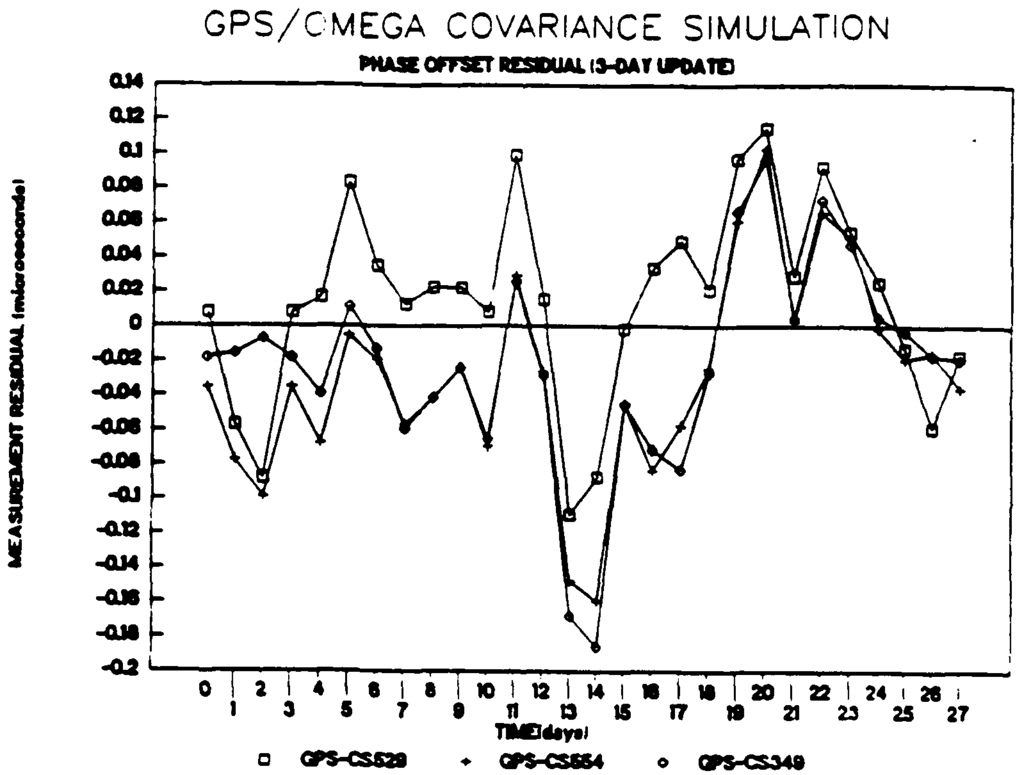


Figure 3.1-2c Phase Offset Residual: GPS-CS529, GPS-CS554, GPS-CS349 (3 Day Update)

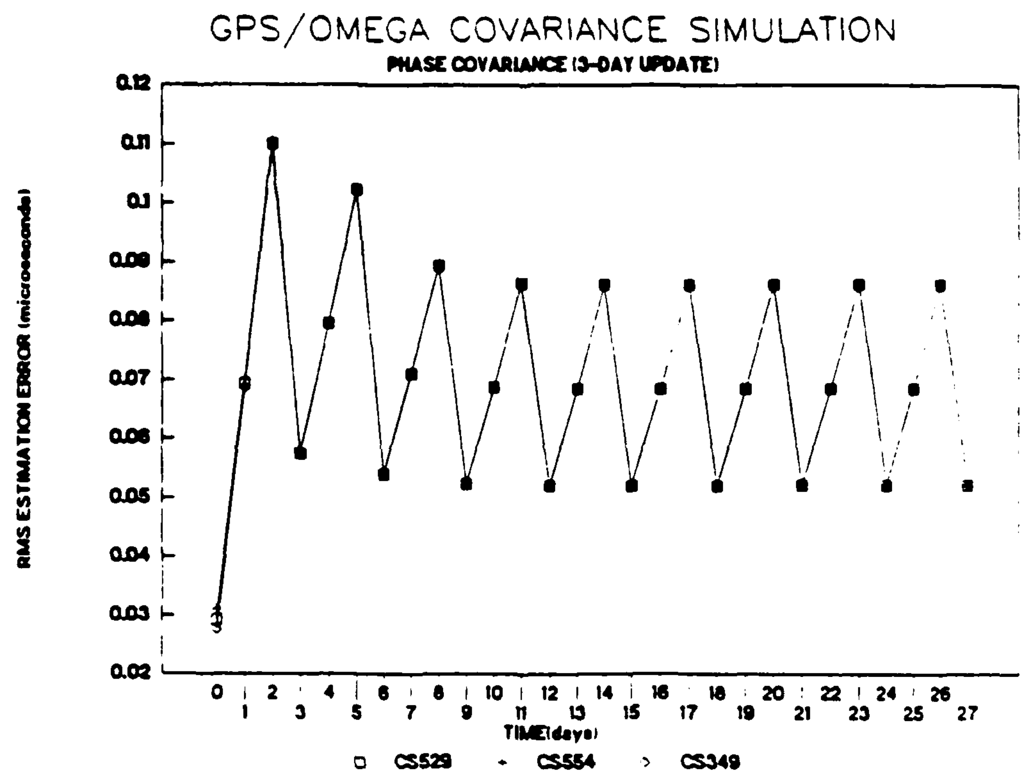


Figure 3.1-2d Phase Covariance (3 Day Update)

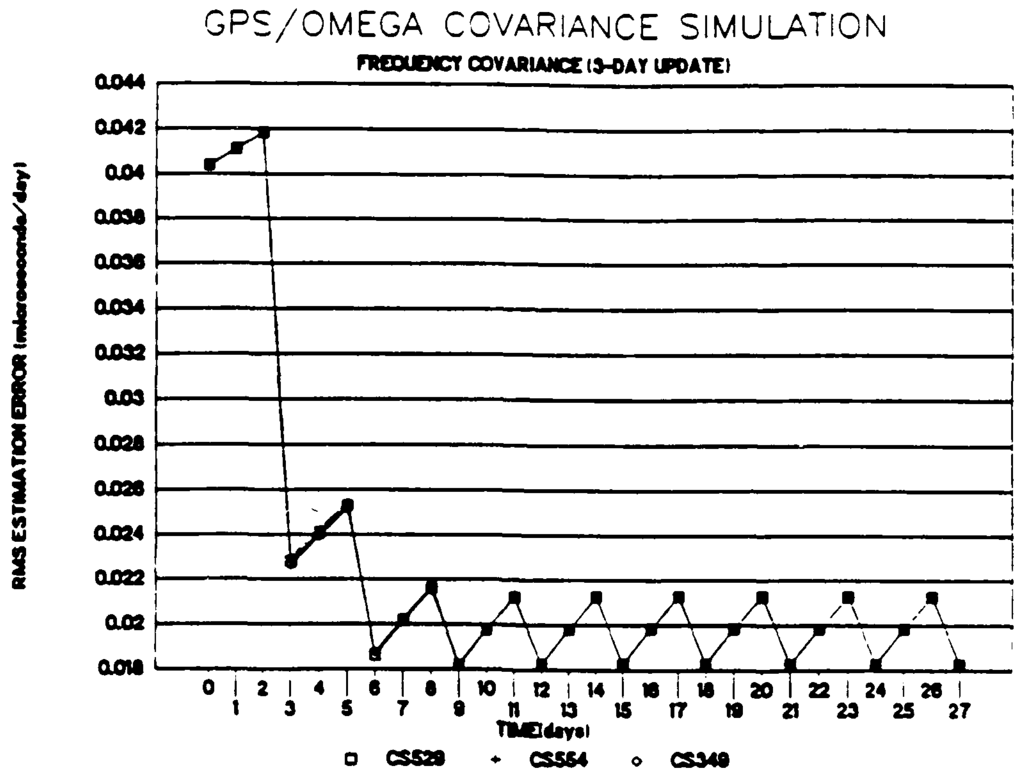


Figure 3.1-2e Frequency Covariance (3 Day Update)

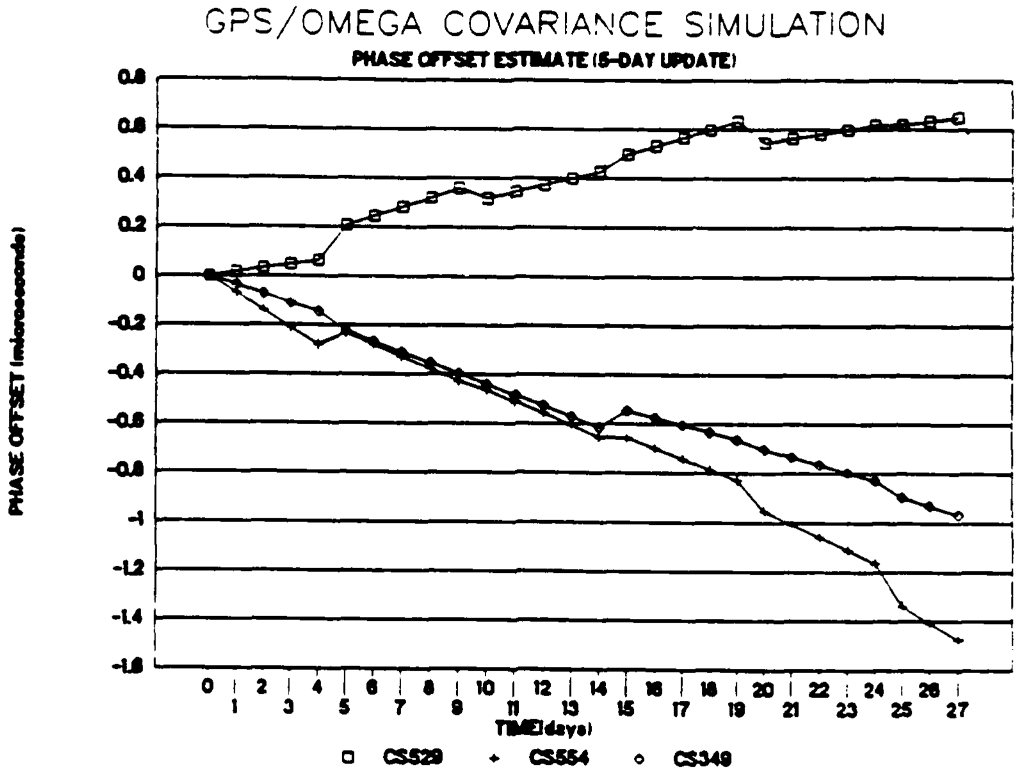


Figure 3.1-3a Phase Offset Estimate (5 Day Update)

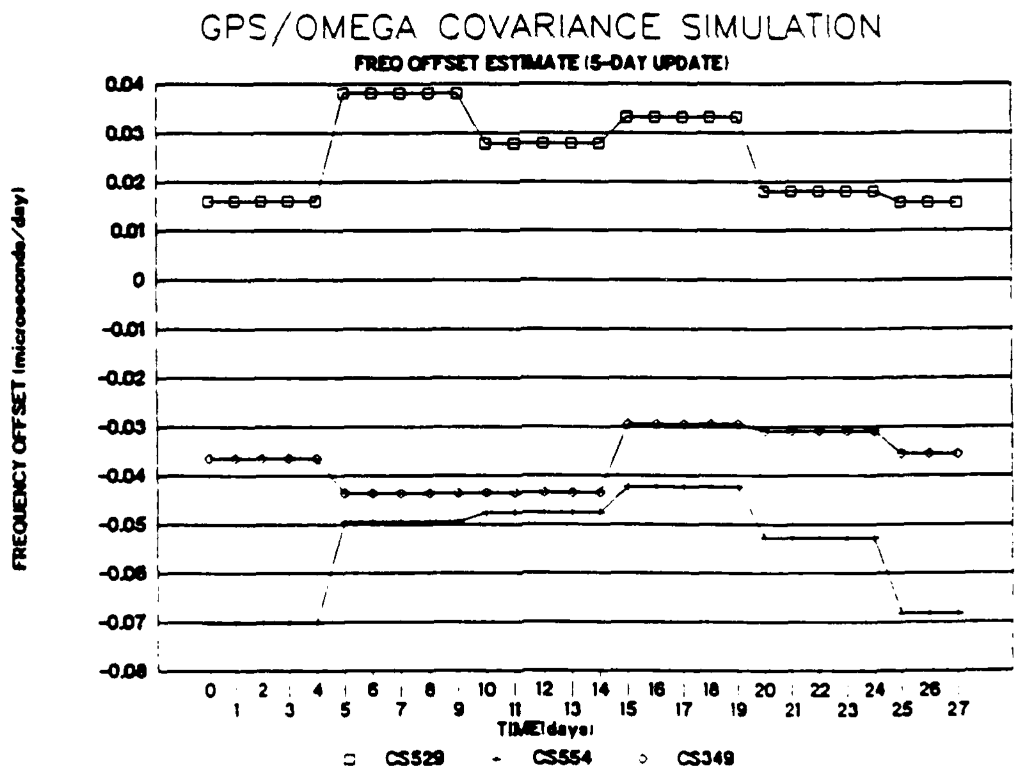


Figure 3.1-3b Frequency Offset Estimate (5 Day Update)

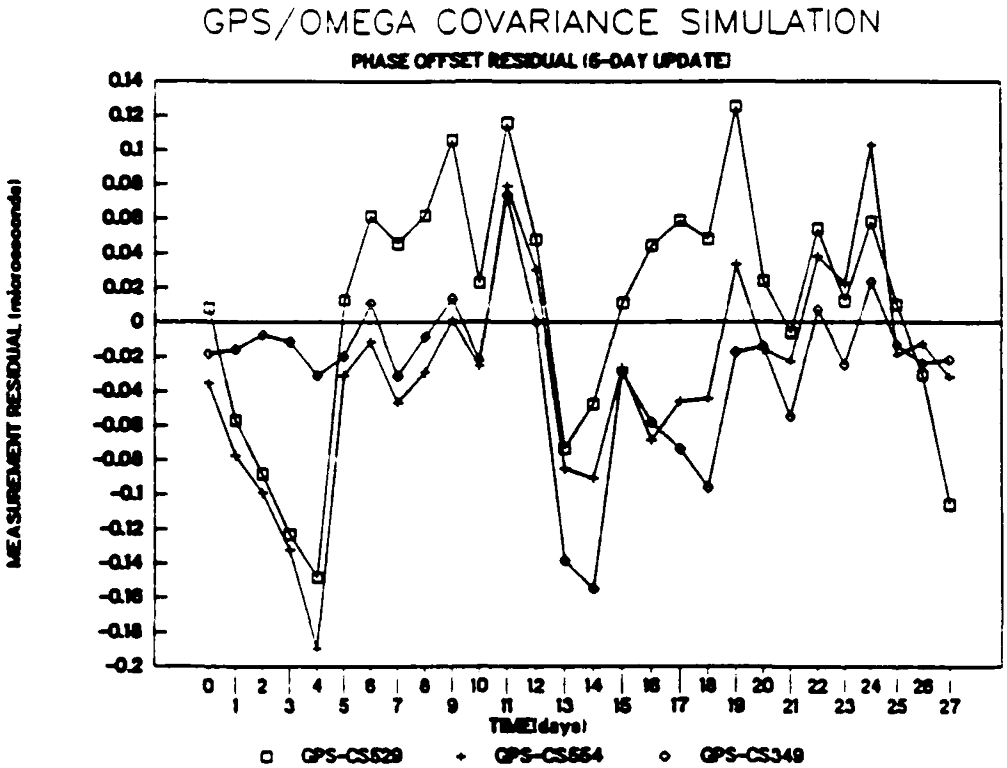


Figure 3.1-3c Phase Offset Residual: GPS-CS529, GPS-CS554, GPS-CS349 (5 Day Update)

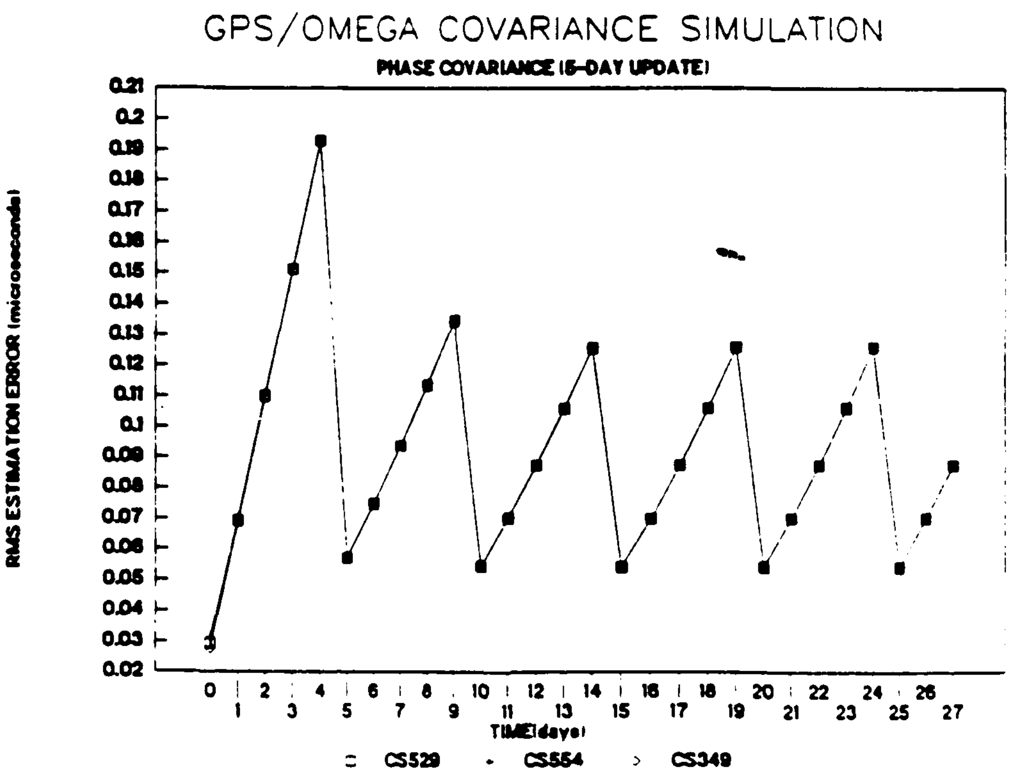


Figure 3.1-3d Phase Covariance (5 Day Update)

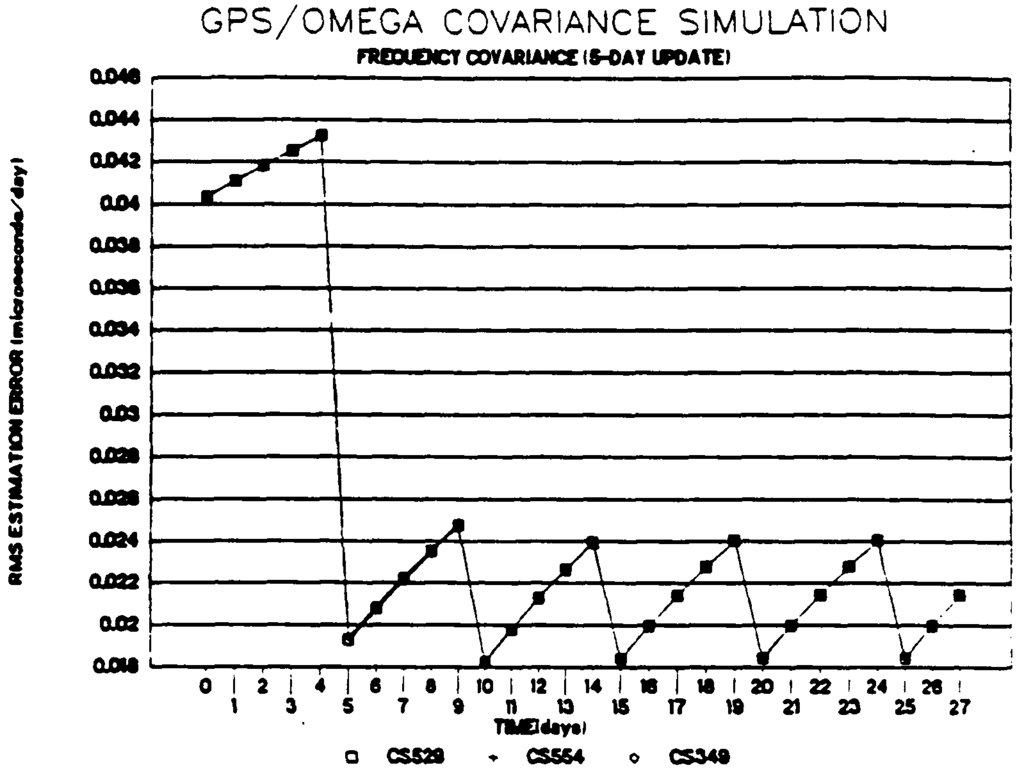


Figure 3.1-3e Frequency Covariance (5 Day Update)

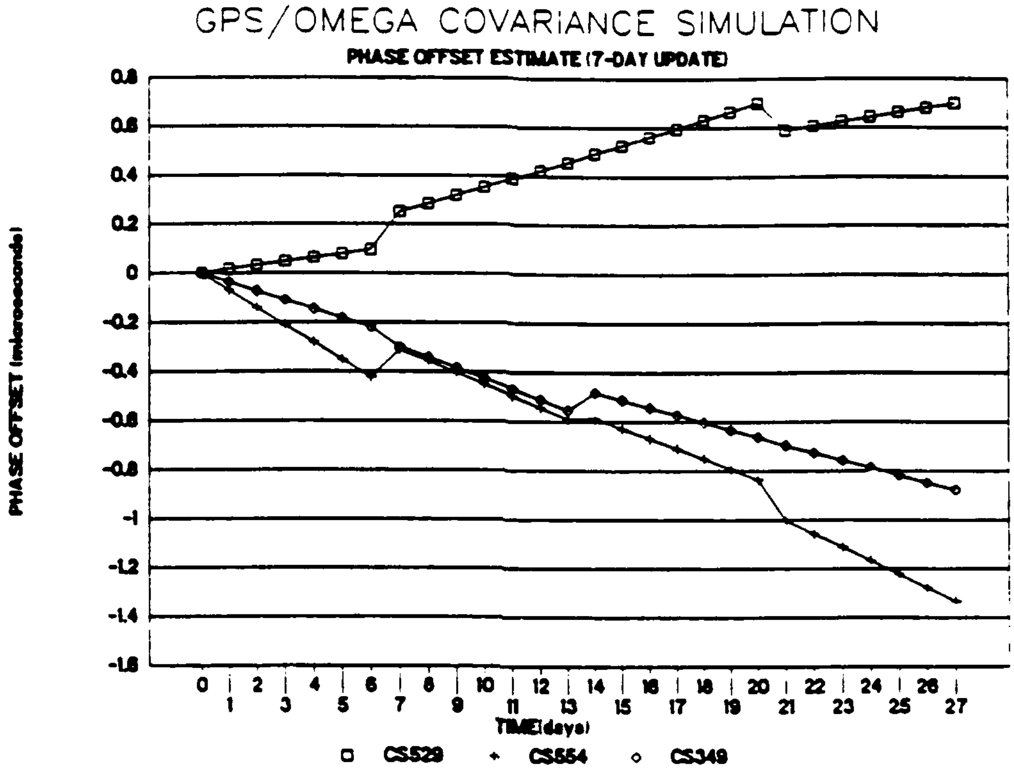


Figure 3.1-4a Phase Offset Estimate (7 Day Update)

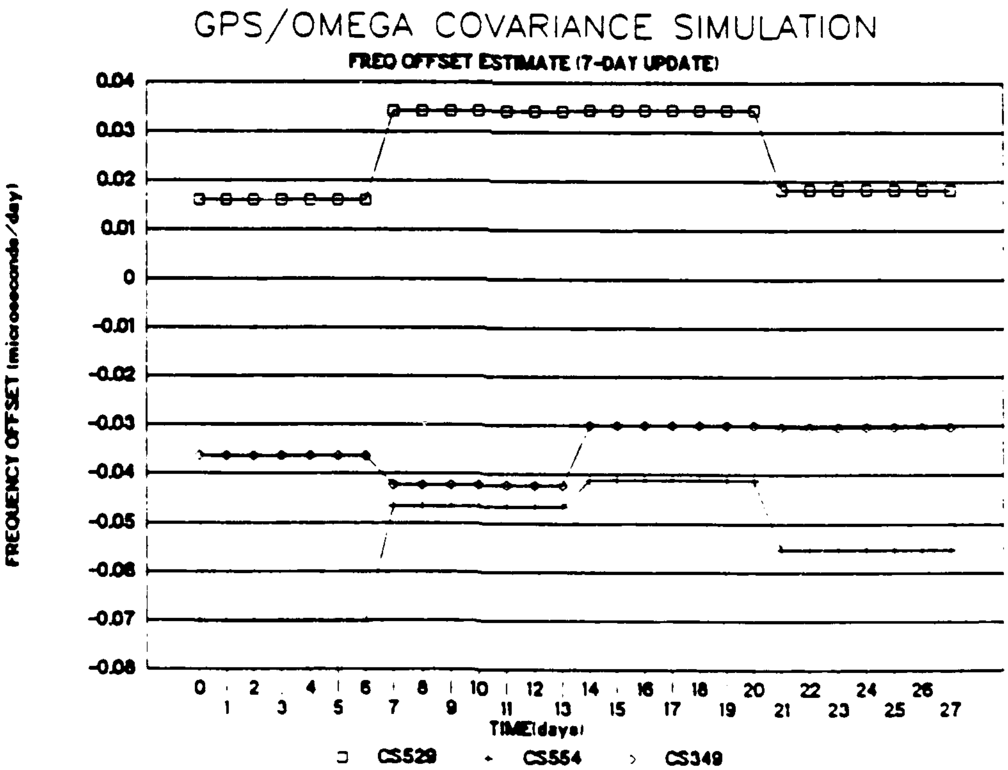


Figure 3.1-4b Frequency Offset Estimate (7 Day Update)

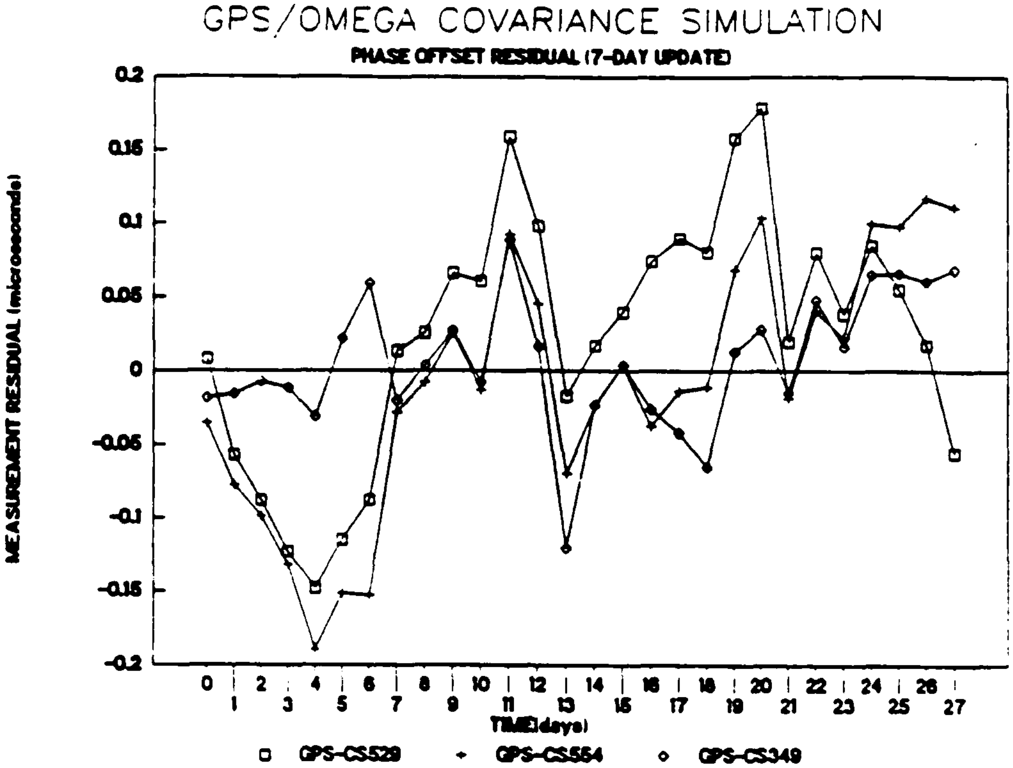


Figure 3.1-4c Phase Offset Residual: GPS-CS529, GPS-CS554, GPS-CS349 (7 Day Update)

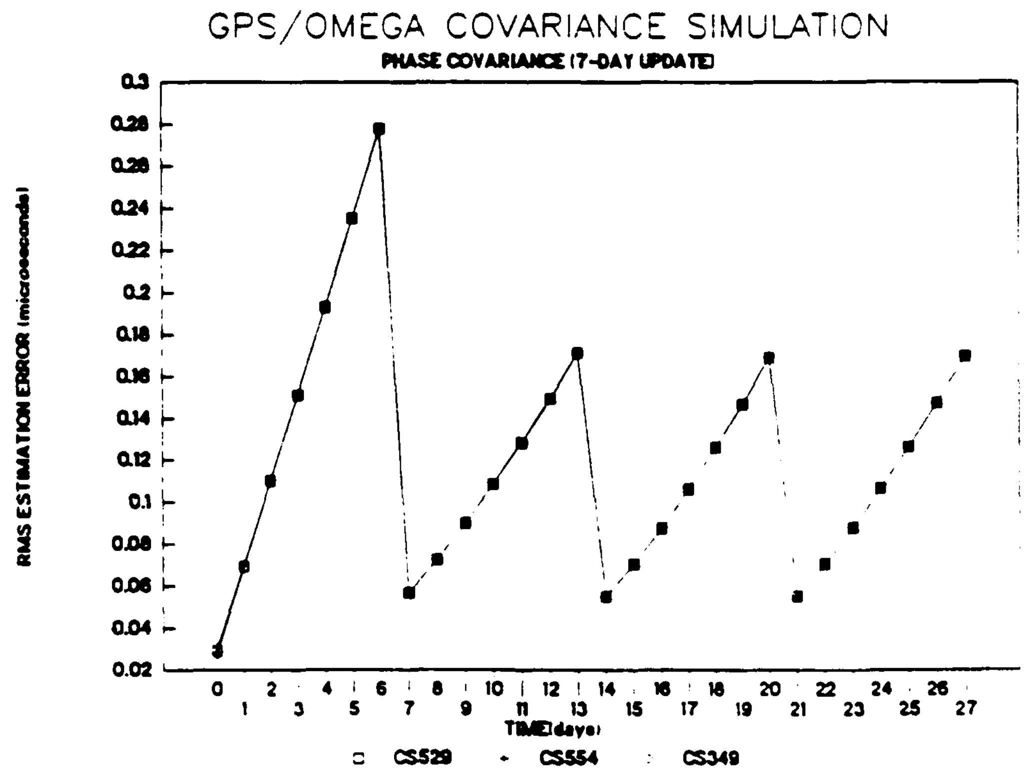


Figure 3.1-4d Phase Covariance (7 Day Update)

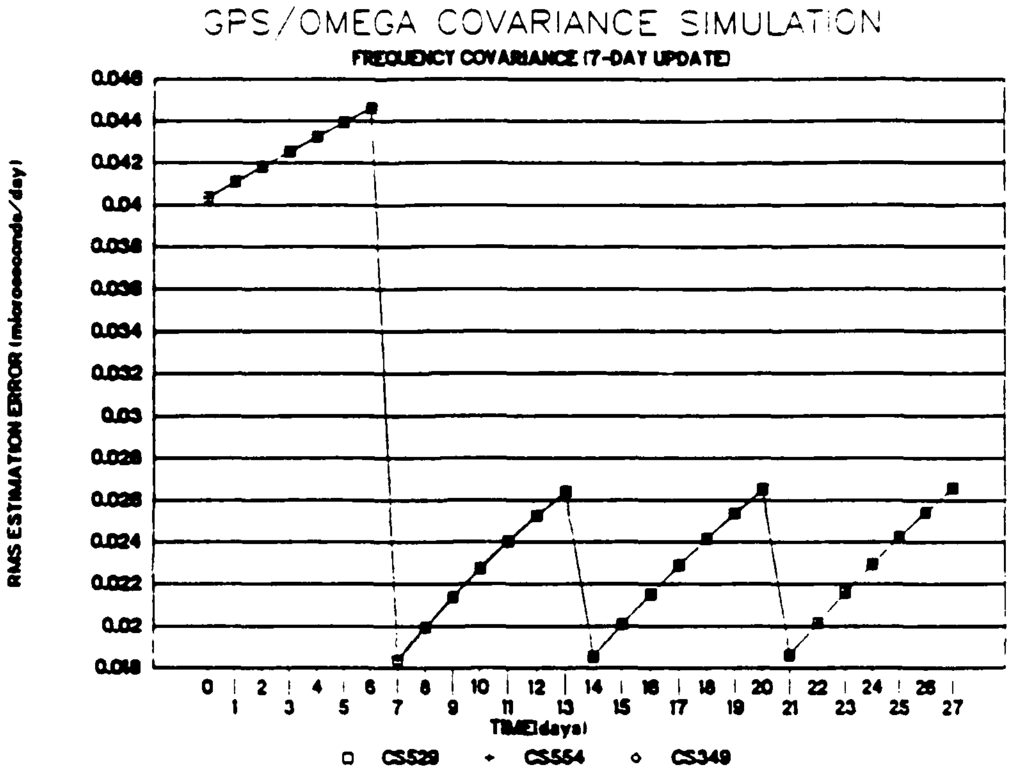


Figure 3.1-4e Frequency Covariance (7 Day Update)

3.2 CONFIGURATION II

Five types of plots were generated for this configuration. They are presented in the following order:

a) Phase Offset Estimate

b) Phase Offset Residual: GPS-CS529, GPS-CS554, GPS-CS349

c) Phase Covariance

This configuration was implemented by the following types of events: GPS1, CLK1 and CLK2. Event "GPS1" identifies GPS-CS529 measurement; event "CLK1" identifies CS529-CS554 measurement and event "CLK2" identifies CS529-CS349 measurement. The remainder of this section contains plots as described above.

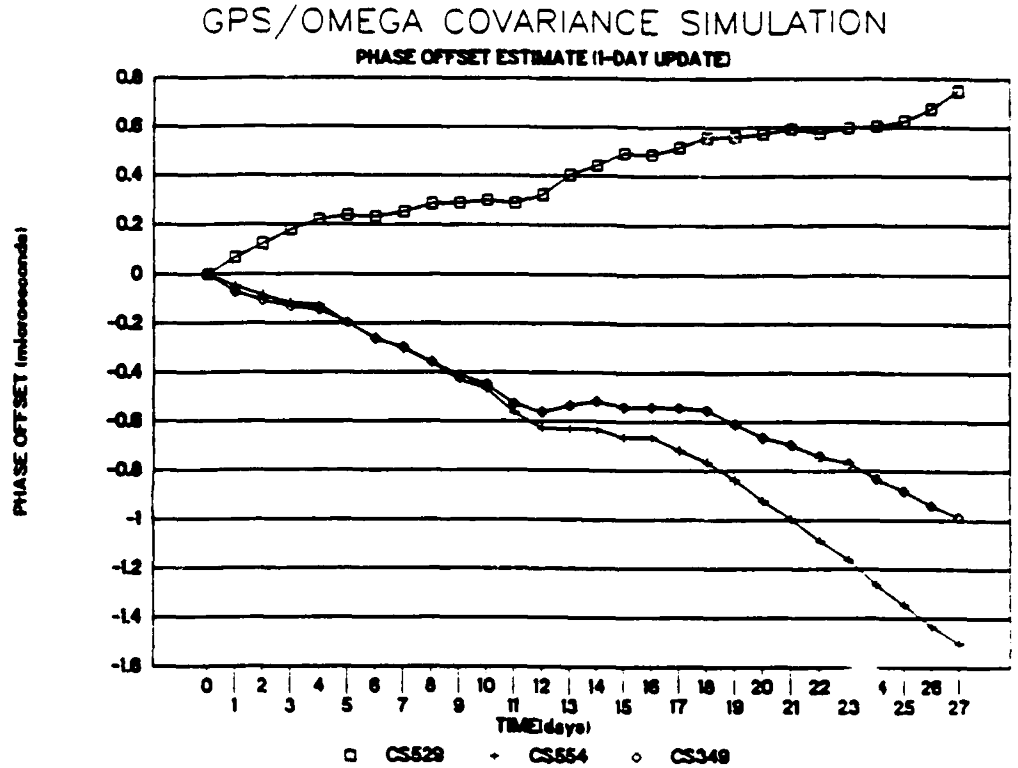


Figure 3.2-1a Phase Offset Estimate (1 Day Update)

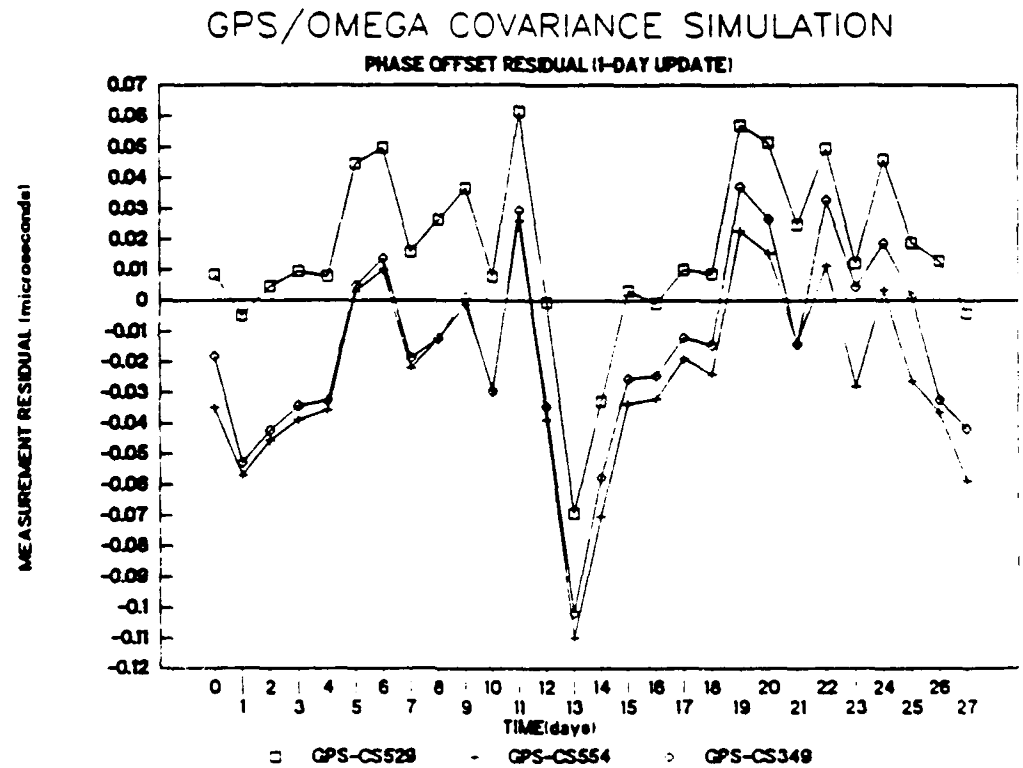


Figure 3.2-1b Phase Offset Residual: GPS-CS529, GPS-CS554, GPS-CS349 (1 Day Update)

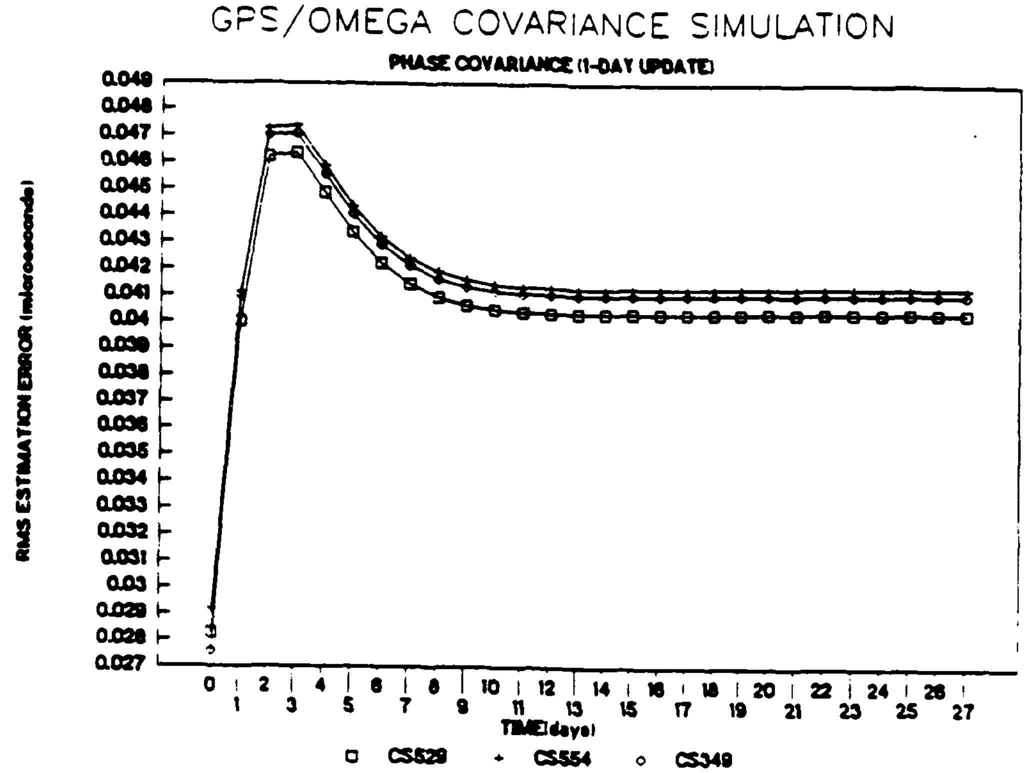


Figure 3.2-1c Phase Covariance (1 Day Update)

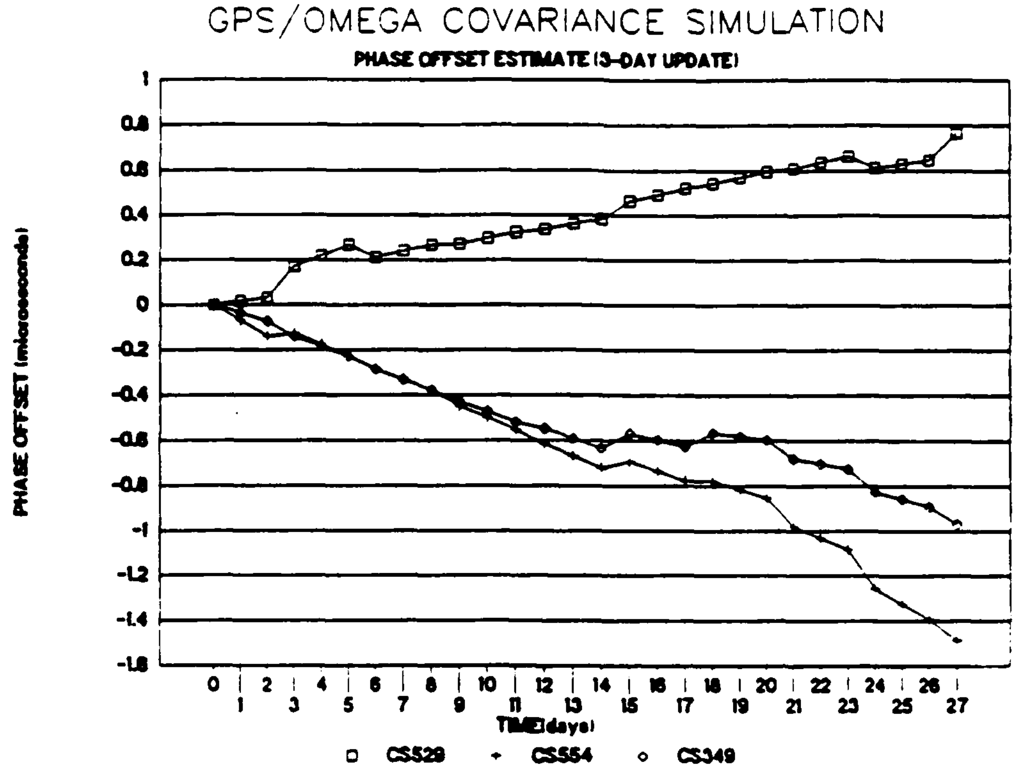


Figure 3.2-2a Phase Offset Estimate (3 Day Update)

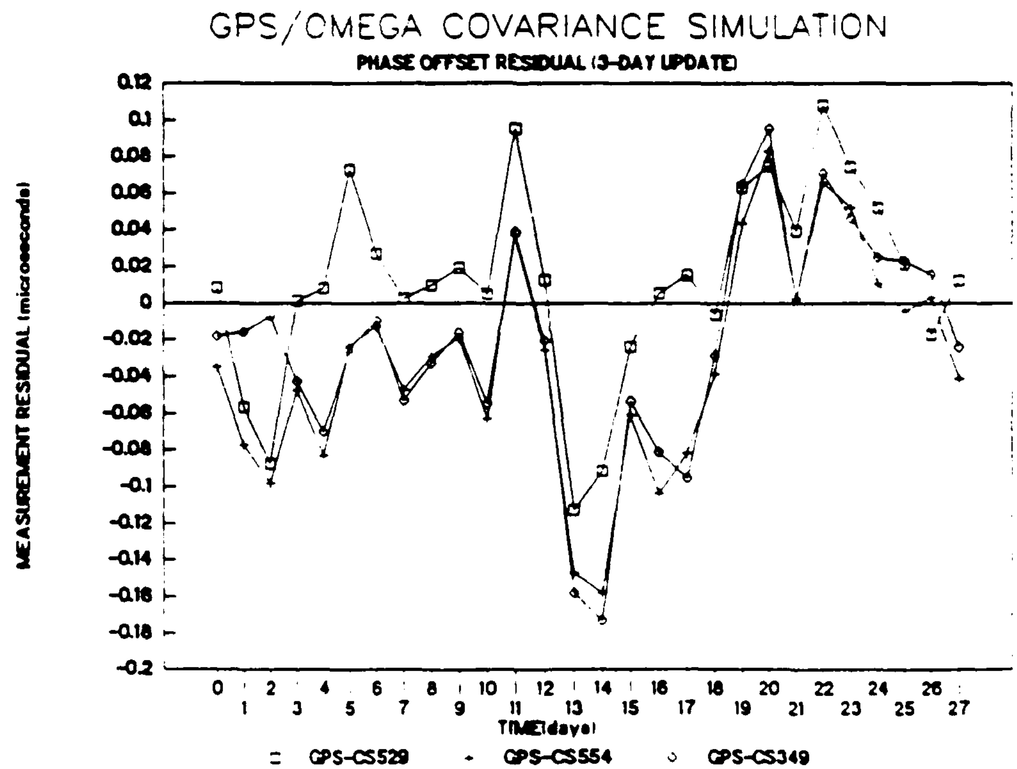


Figure 3.2-2b Phase Offset Residual: GPS-CS529, GPS-CS554, GPS-CS349 (3 Day Update)

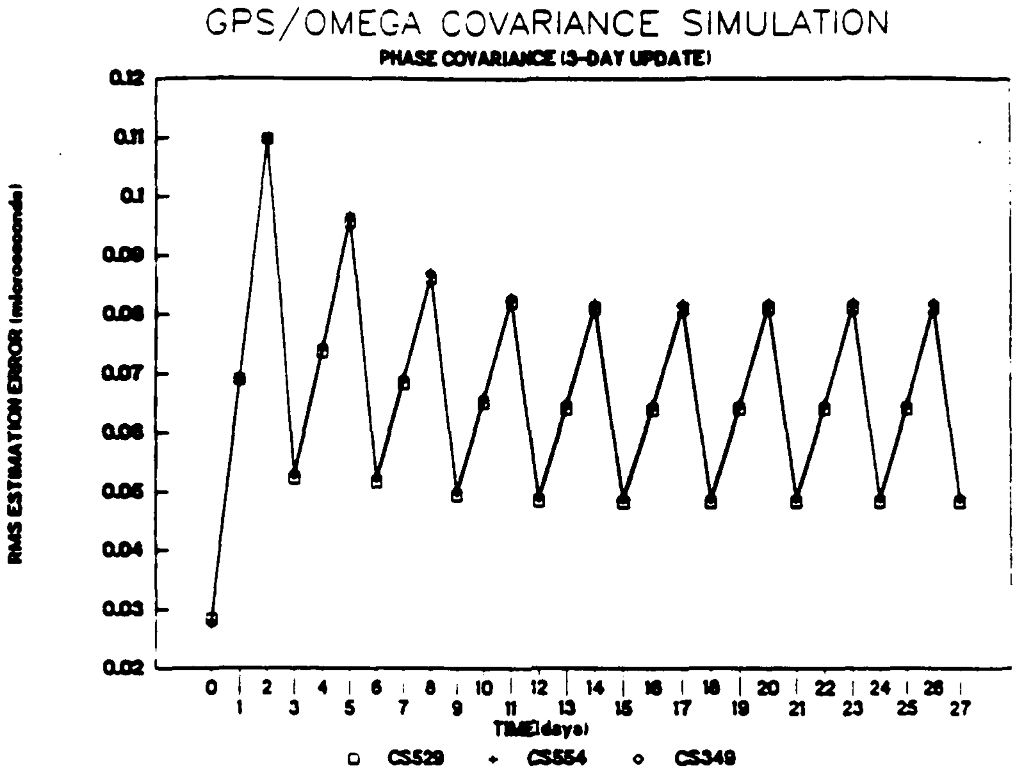


Figure 3.2-2c Phase Covariance (3 Day Update)

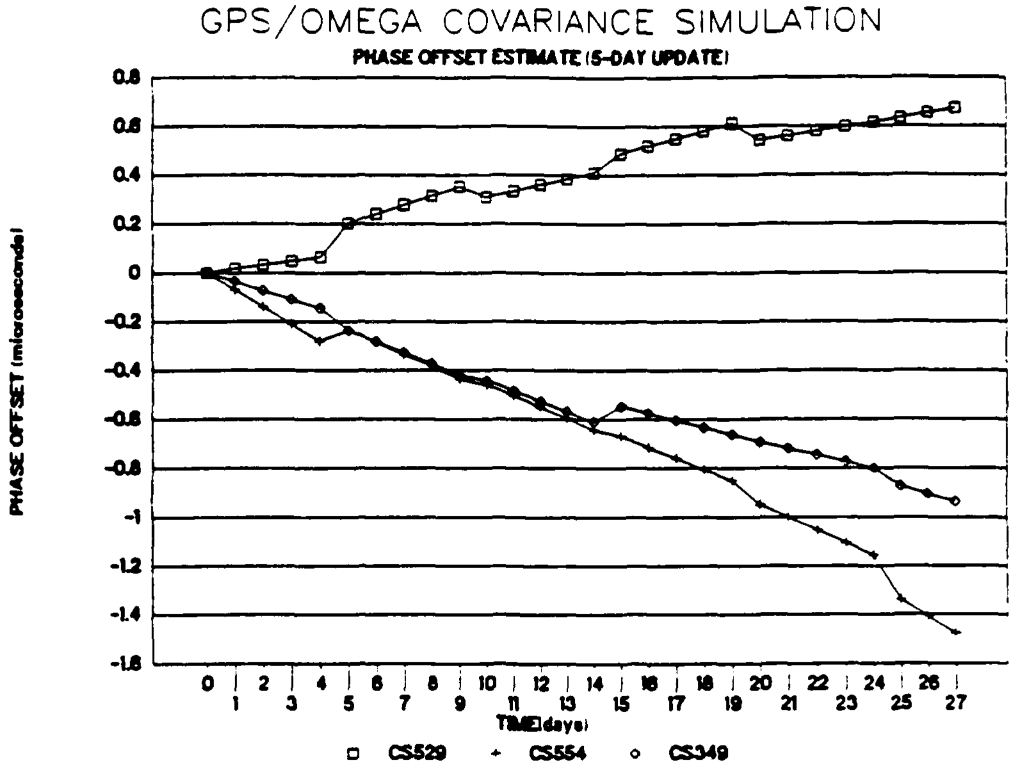


Figure 3.2-3a Phase Offset Estimate (5 Day Update)

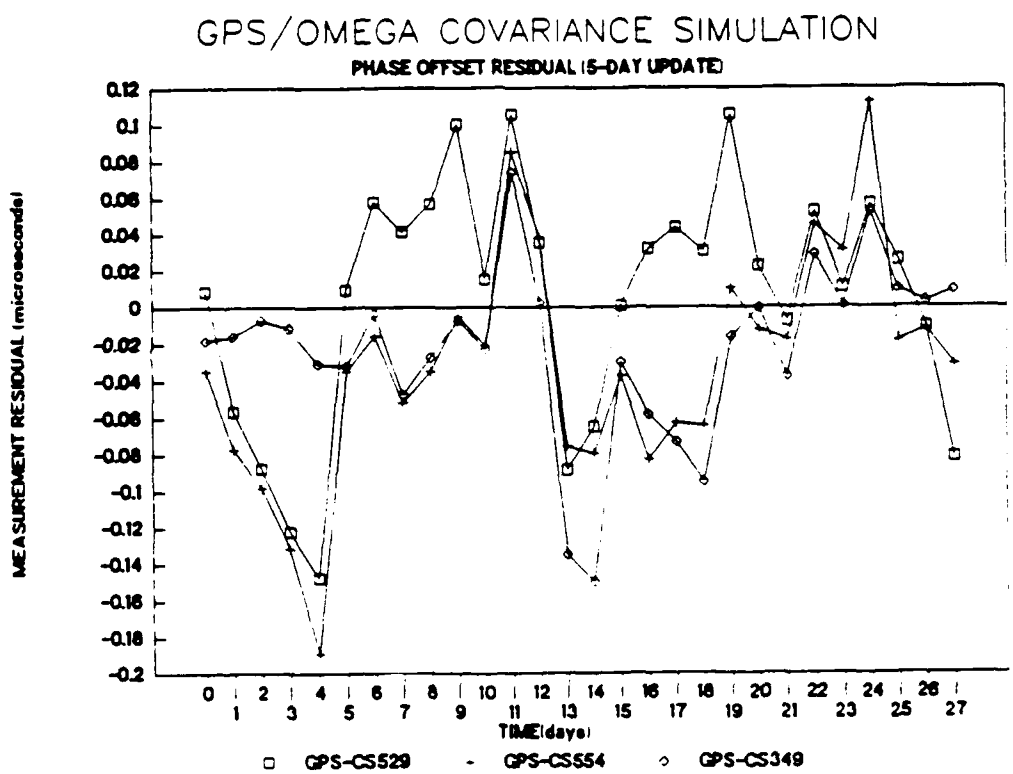


Figure 3.2-3b Phase Offset Residual: GPS-CS529, GPS-CS554, GPS-CS349 (5 Day Update)

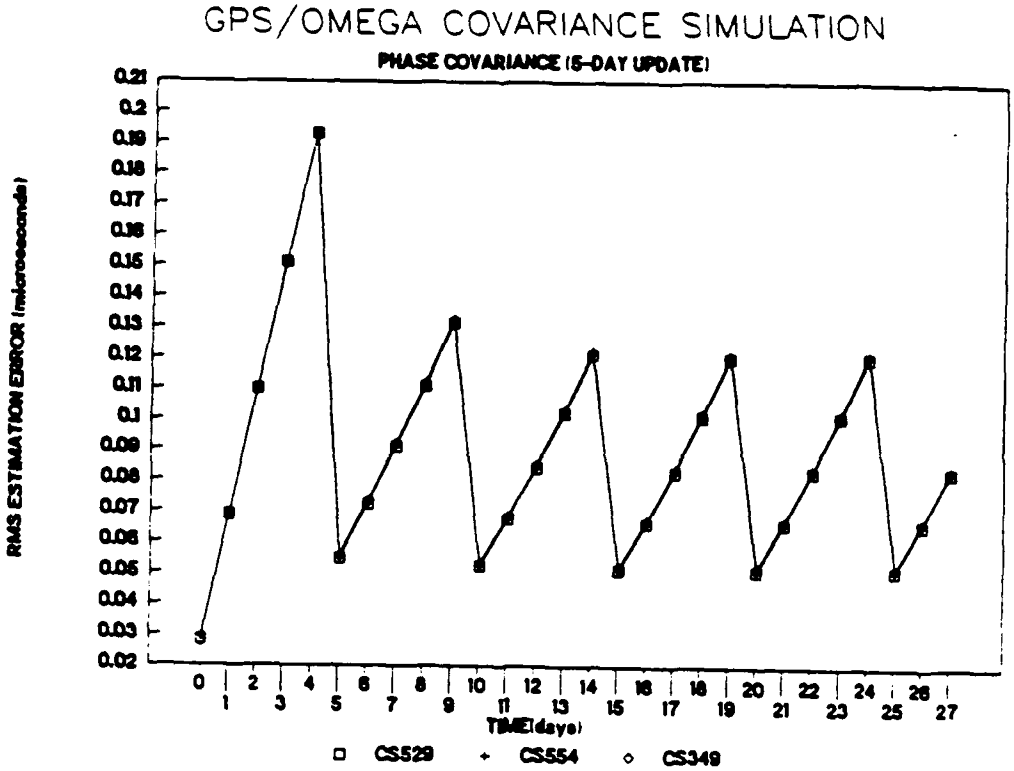


Figure 3.2-3c Phase Covariance (5 Day Update)

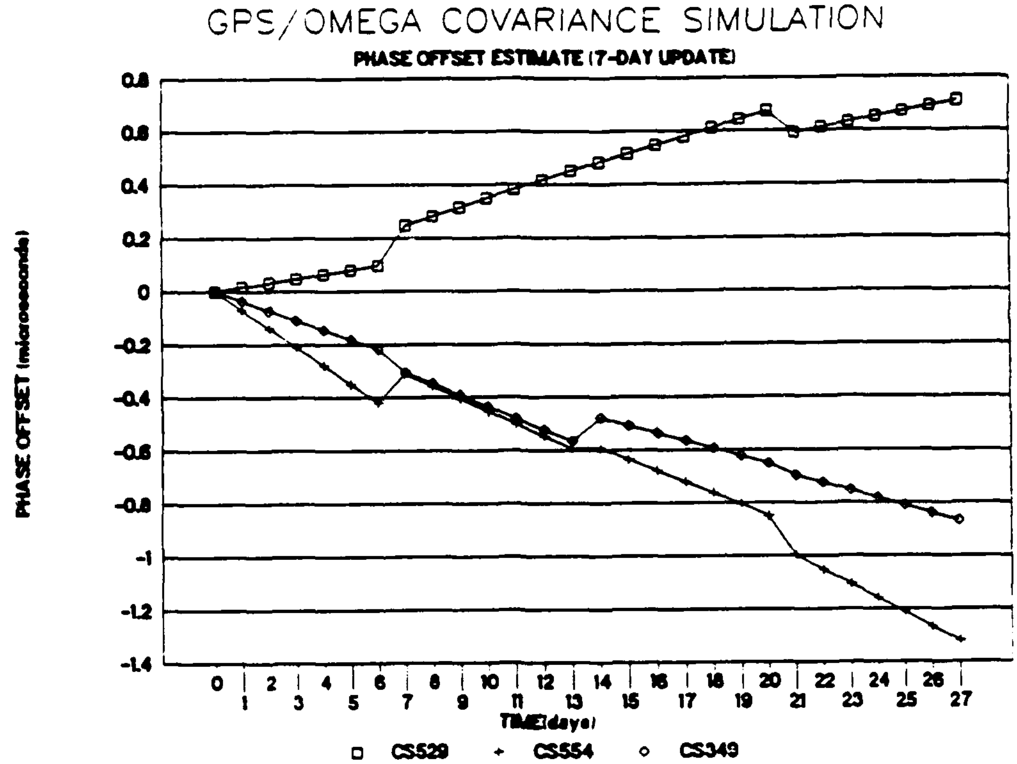


Figure 3.2-4a Phase Offset Estimate (7 Day Update)

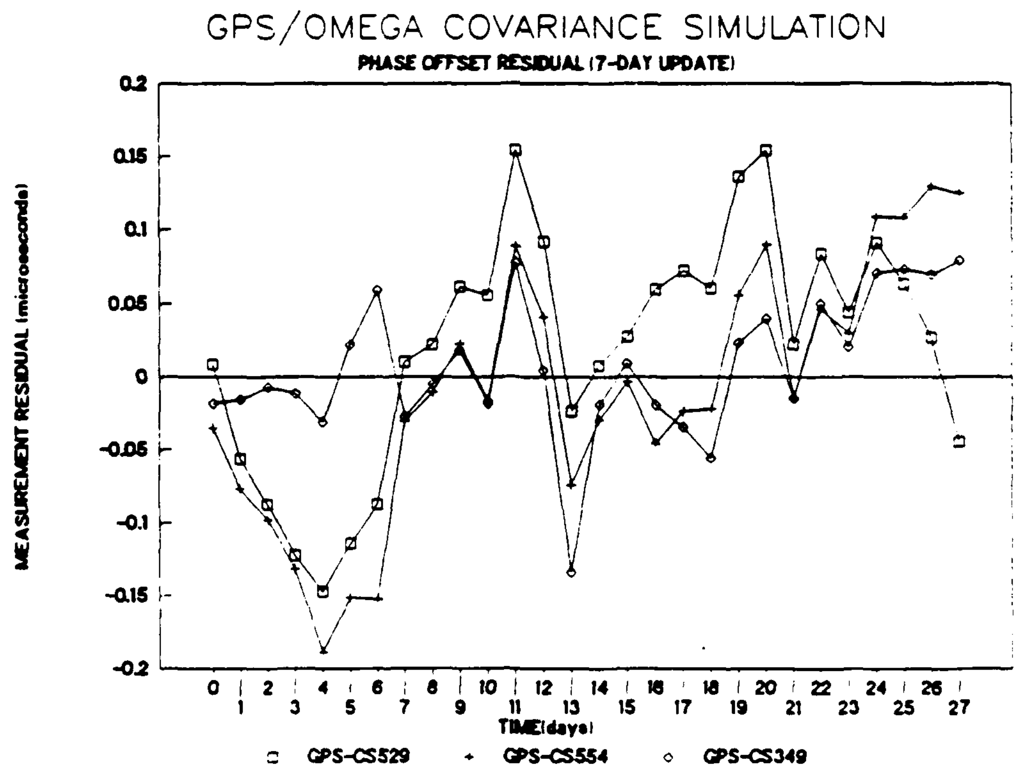


Figure 3.2-4b Phase Offset Residual: GPS-CS529, GPS-CS554, GPS-CS349 (7 Day Update)

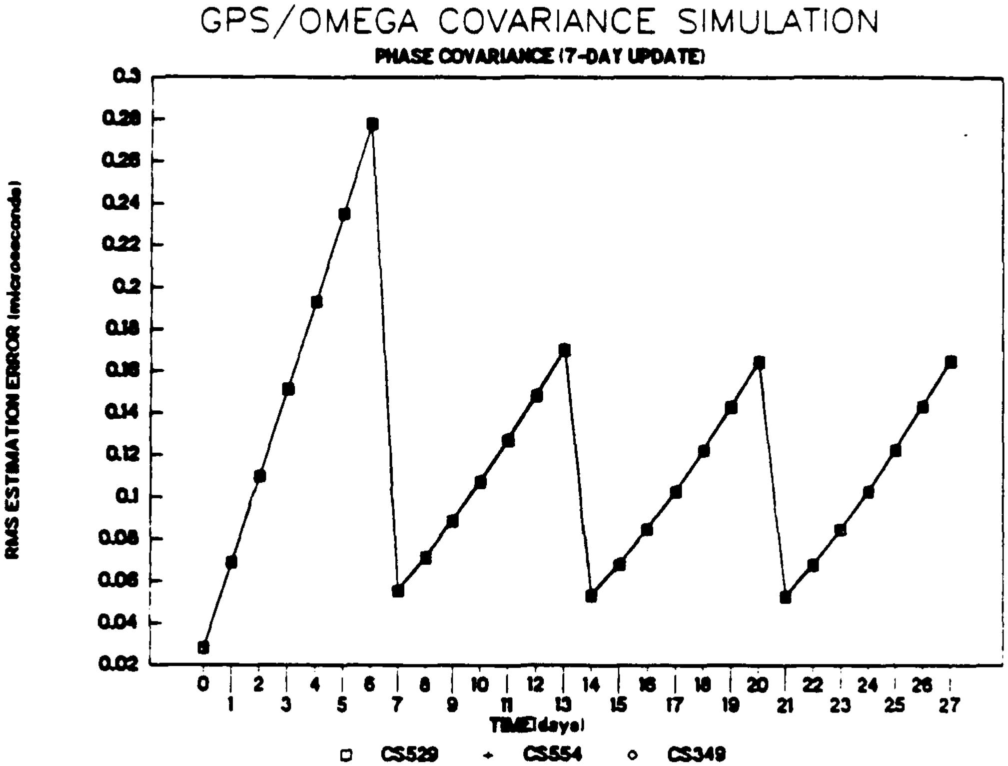


Figure 3.2-4c Phase Covariance (7 Day Update)

3.3 CONFIGURATION III

Three types of plots were generated for this configuration. They are presented in the following order:

a) Phase Offset Estimate

b) Phase Offset Residual: GPS-CS529, GPS-CS554

c) Phase Covariance

This configuration was implemented by the following types of events: GPS1 and CLK1. Event "GPS1" identifies GPS-CS529 measurement and event "CLK1" identifies CS529-CS554 measurement. The remainder of this section contains plots as described above.

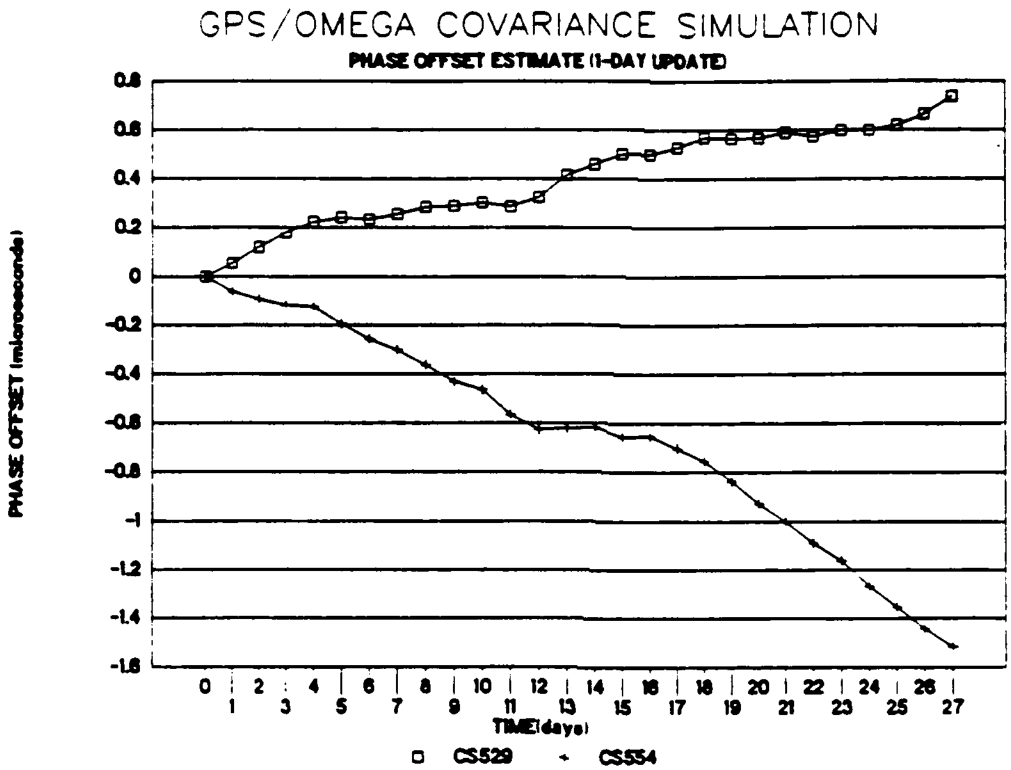


Figure 3.3-1a Phase Offset Estimate (1 Day Update)

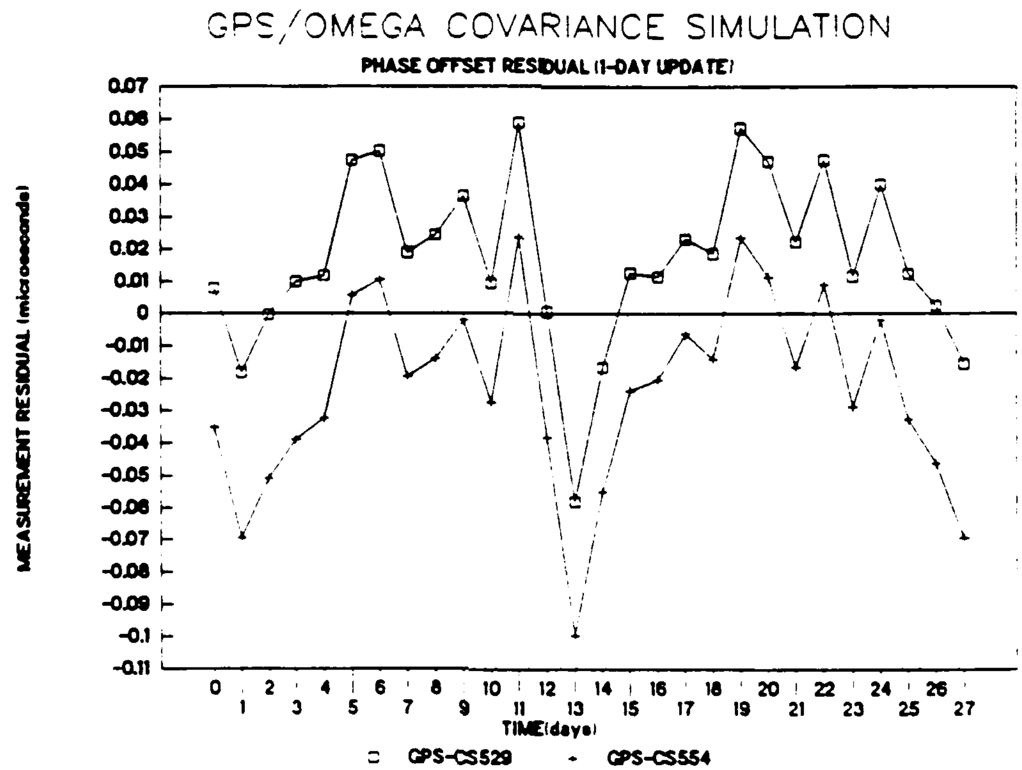


Figure 3.3-1b Phase Offset Residual: GPS-CS529, GPS-CS554 (1 Day Update)

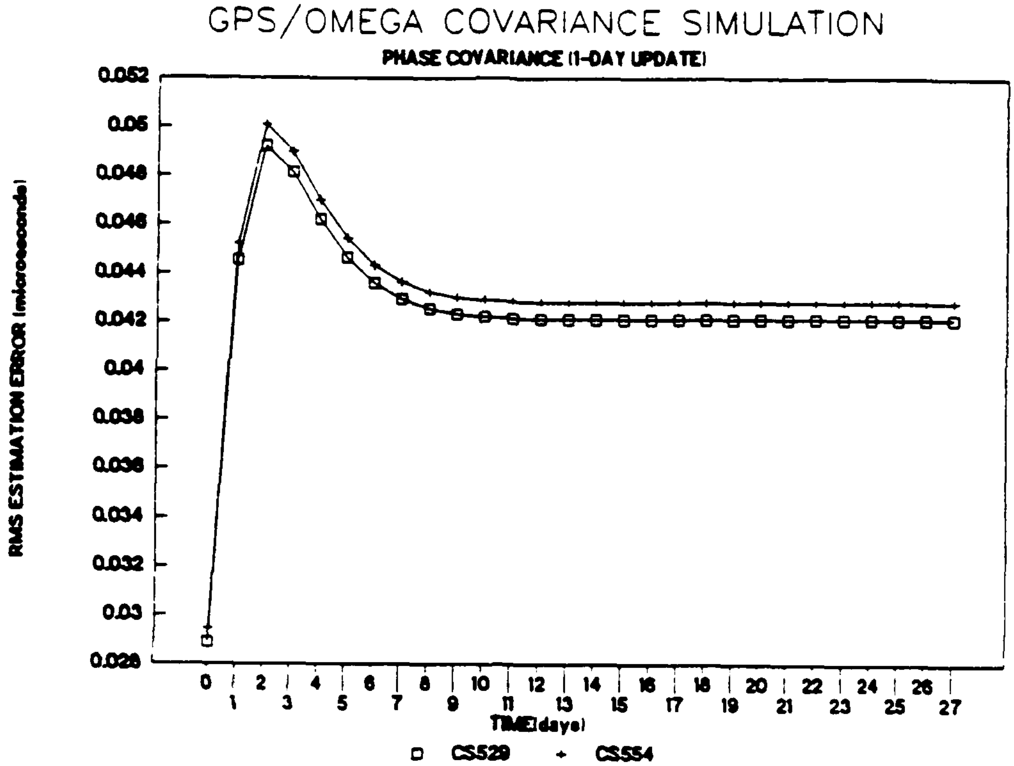


Figure 3.3-1c Phase Covariance (1 Day Update)

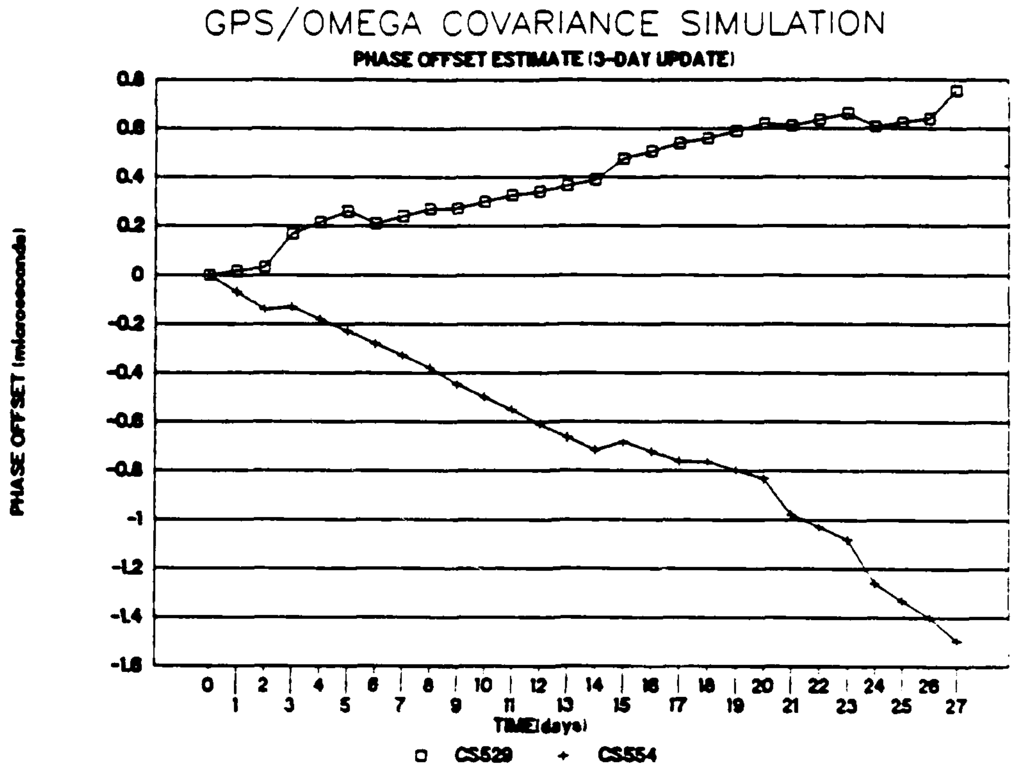


Figure 3.3-2a Phase Offset Estimate (3 Day Update)

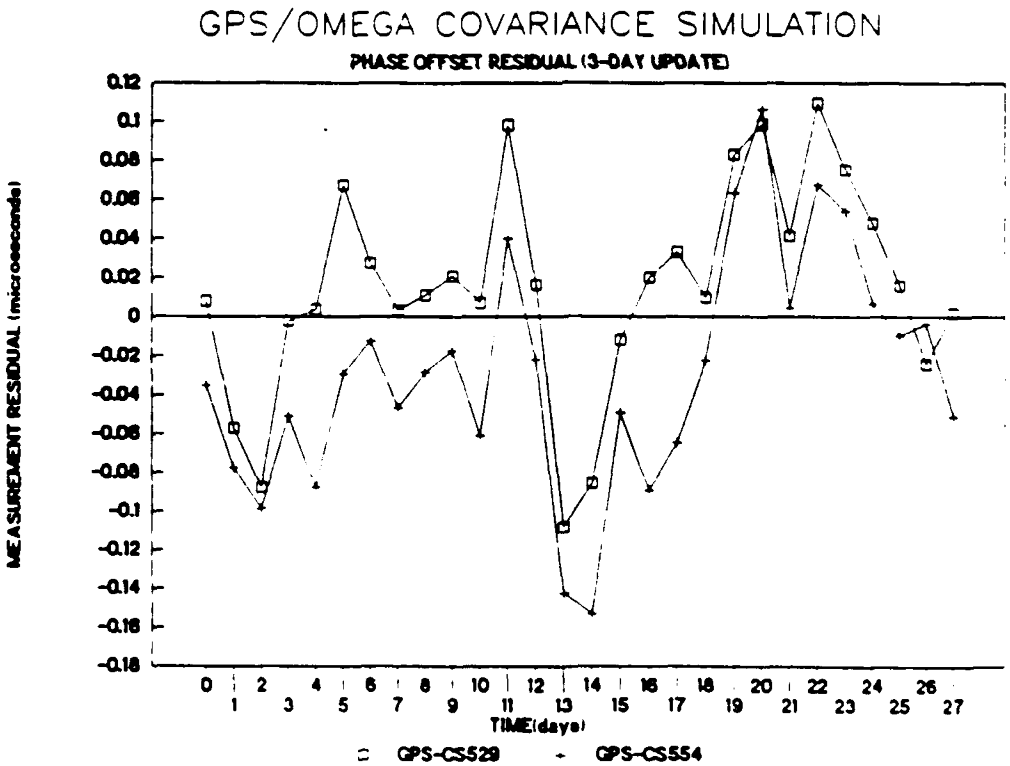


Figure 3.3-2b Phase Offset Residual: GPS-CS529, GPS-CS554 (3 Day Update)

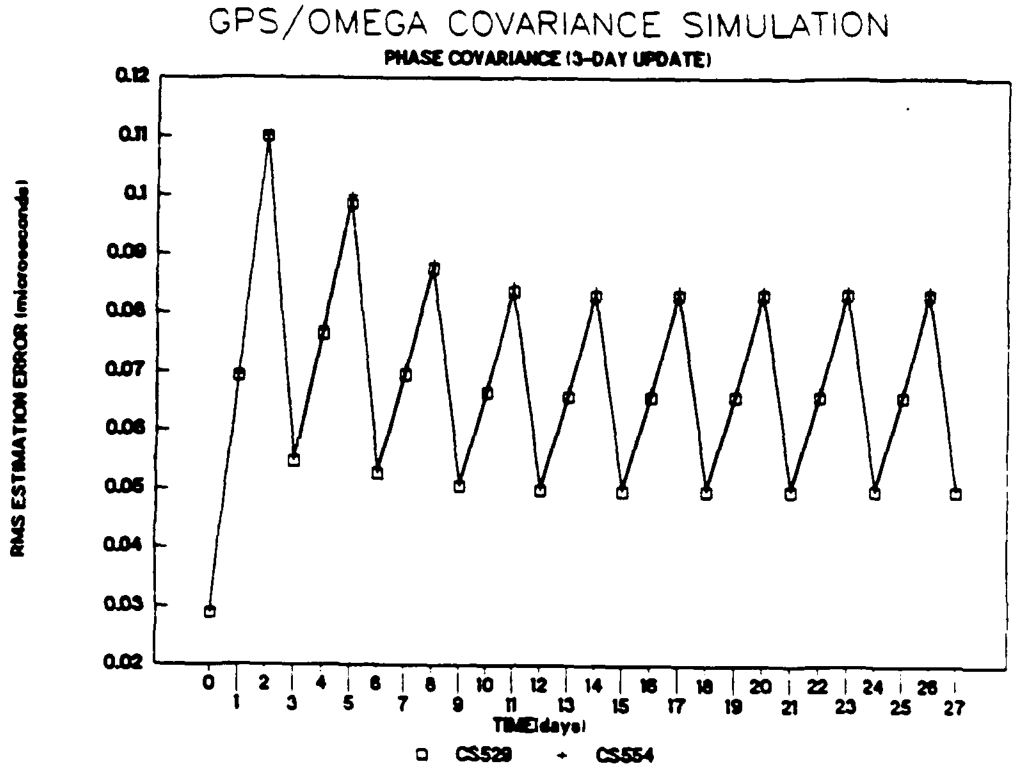


Figure 3.3-2c Phase Covariance (3 Day Update)

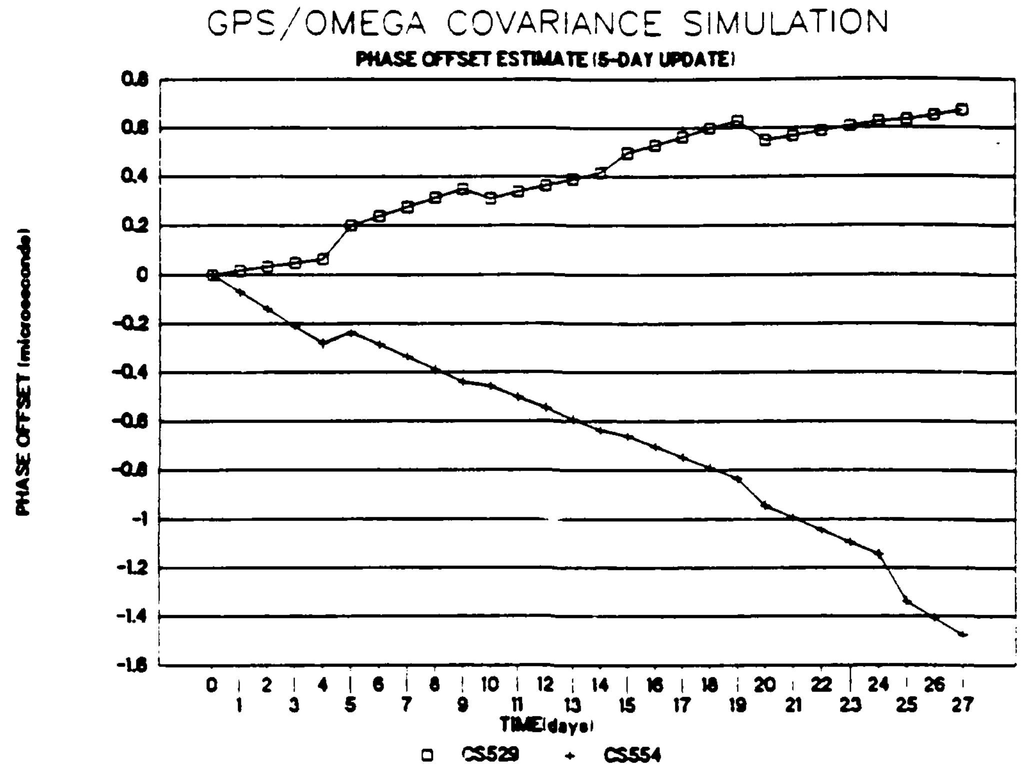


Figure 3.3-3a Phase Offset Estimate (5 Day Update)

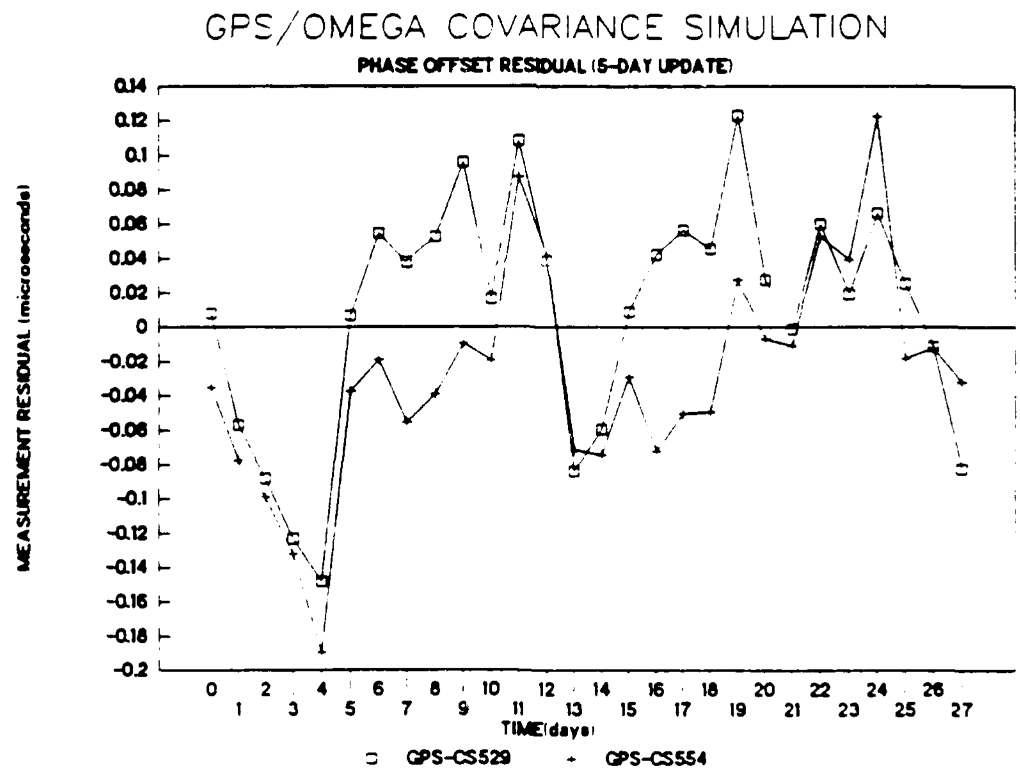


Figure 3.3-3b Phase Offset Residual: GPS-CS529, GPS-CS554 (5 Day Update)

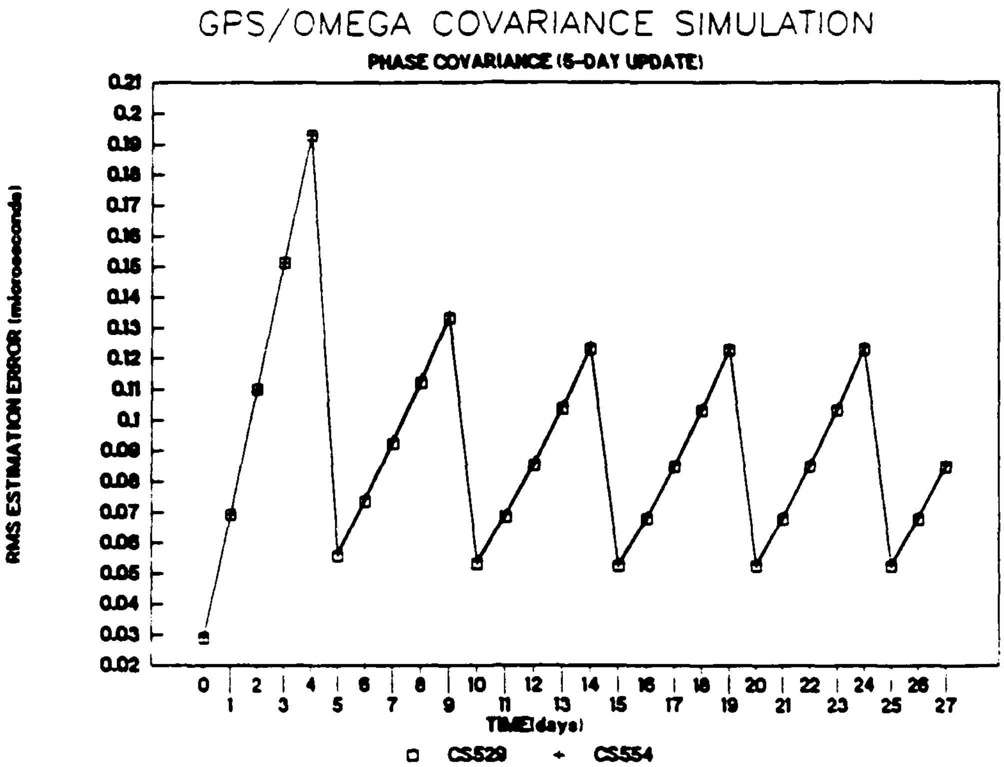


Figure 3.3-3c Phase Covariance (5 Day Update)

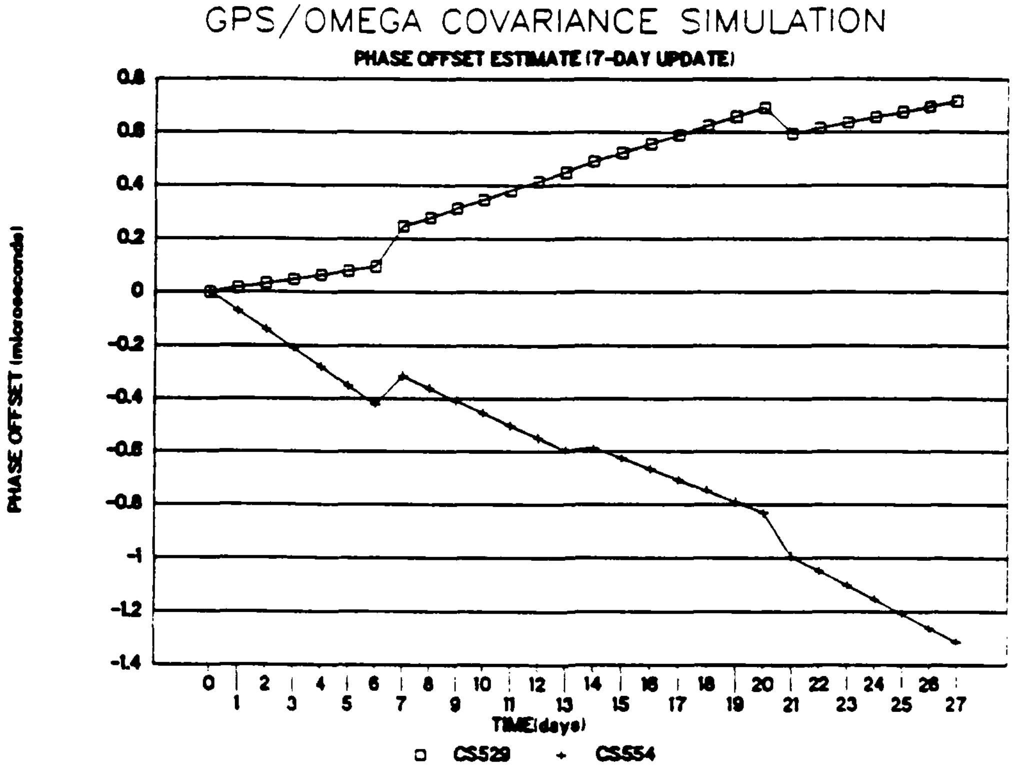


Figure 3.3-4a Phase Offset Estimate (7 Day Update)

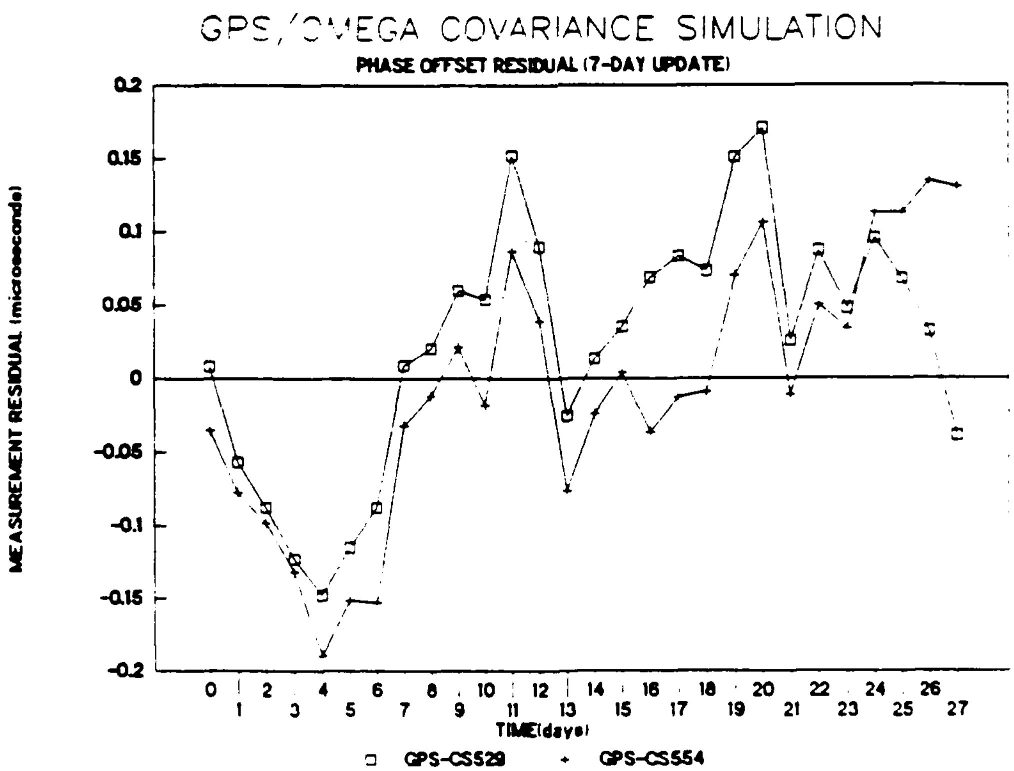


Figure 3.3-4b Phase Offset Residual: GPS-CS529, GPS-CS554 (7 Day Update)

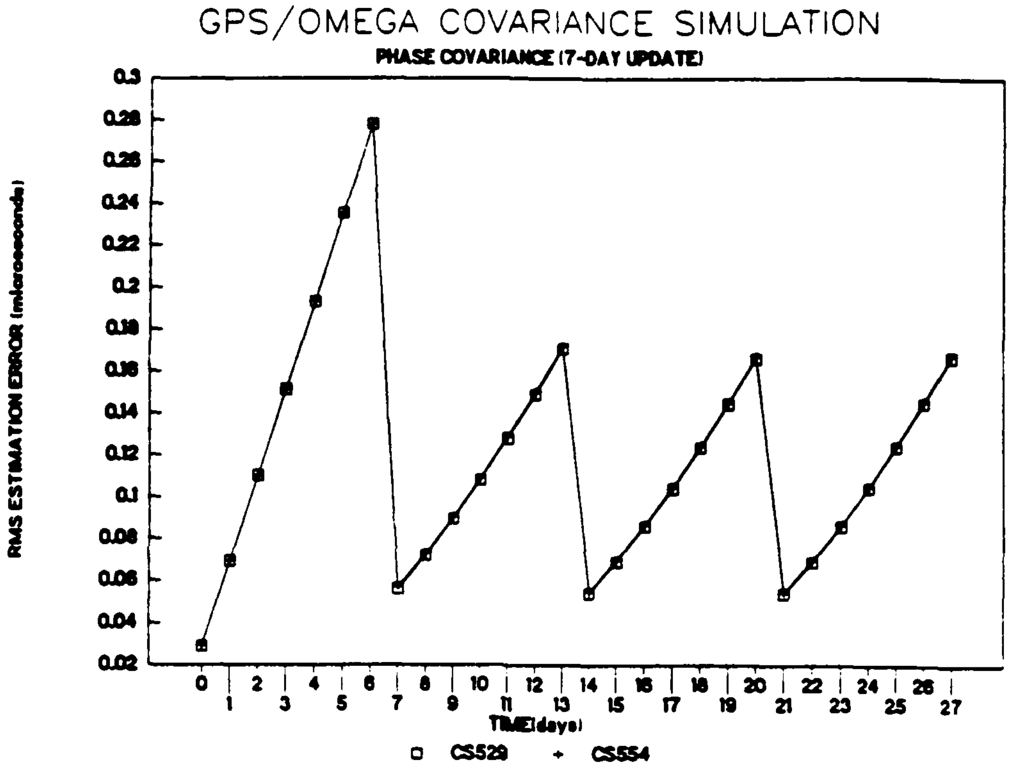


Figure 3.3-4c Phase Covariance (7 Day Update)

3.4 CONFIGURATION IV

Three types of plots were generated for this configuration. They are presented in the following order:

a) Phase Offset Estimate

b) Phase Offset Residual: GPS-CS529, GPS-CS554, GPS-CS349

c) Phase Covariance

This configuration was implemented by the following types of events: CLK1 and CLK2. Event "CLK1" identifies CS529-CS554 measurement and event "CLK2" identifies CS529-CS349 measurement. The remainder of this section contains plots as described above.

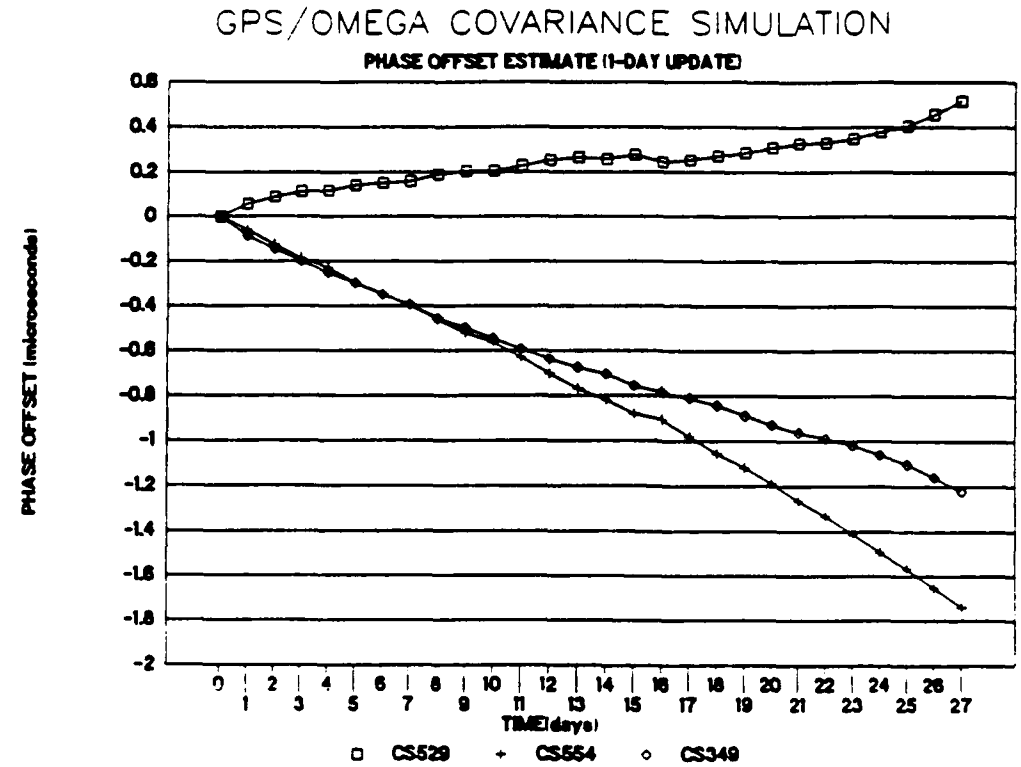


Figure 3.4-1a Phase Offset Estimate (1 Day Update)

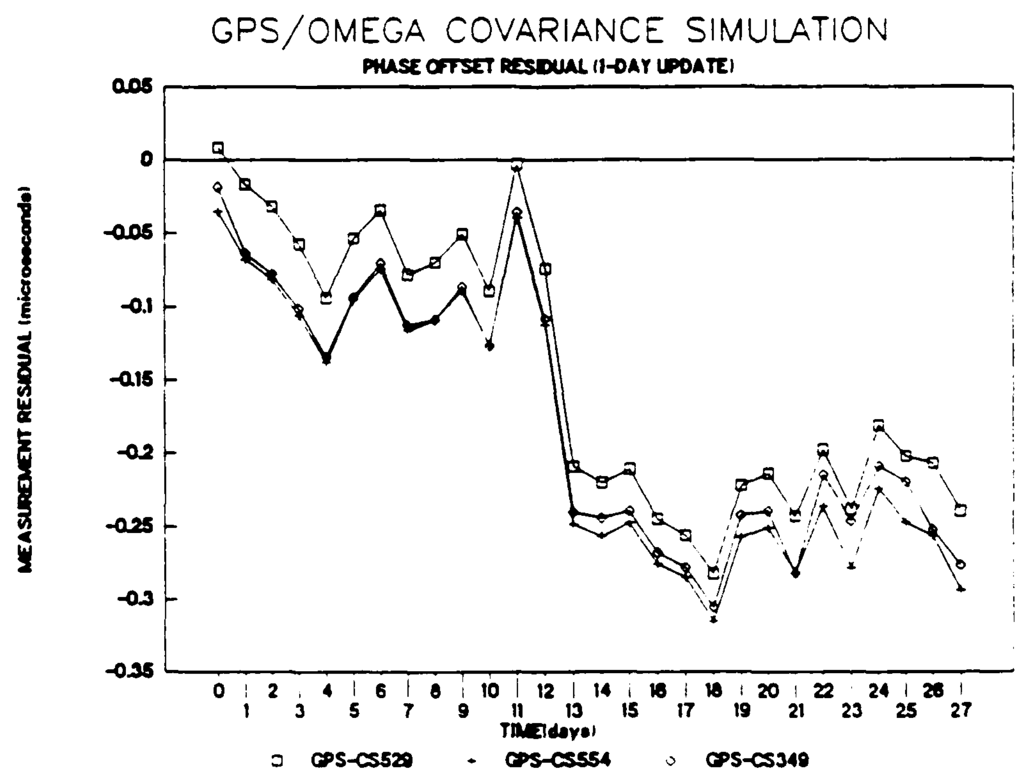


Figure 3.4-1b Phase Offset Residual: GPS-CS529, GPS-CS554, GPS-CS349 (1 Day Update)

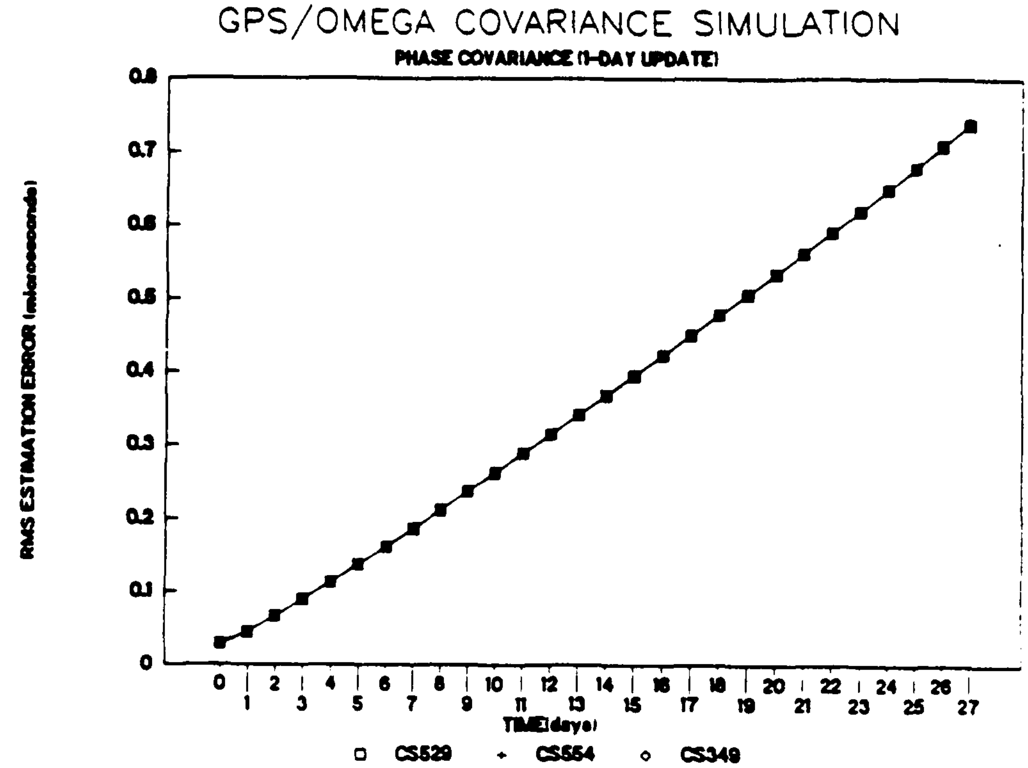


Figure 3.4-1c Phase Covariance (1 Day Update)

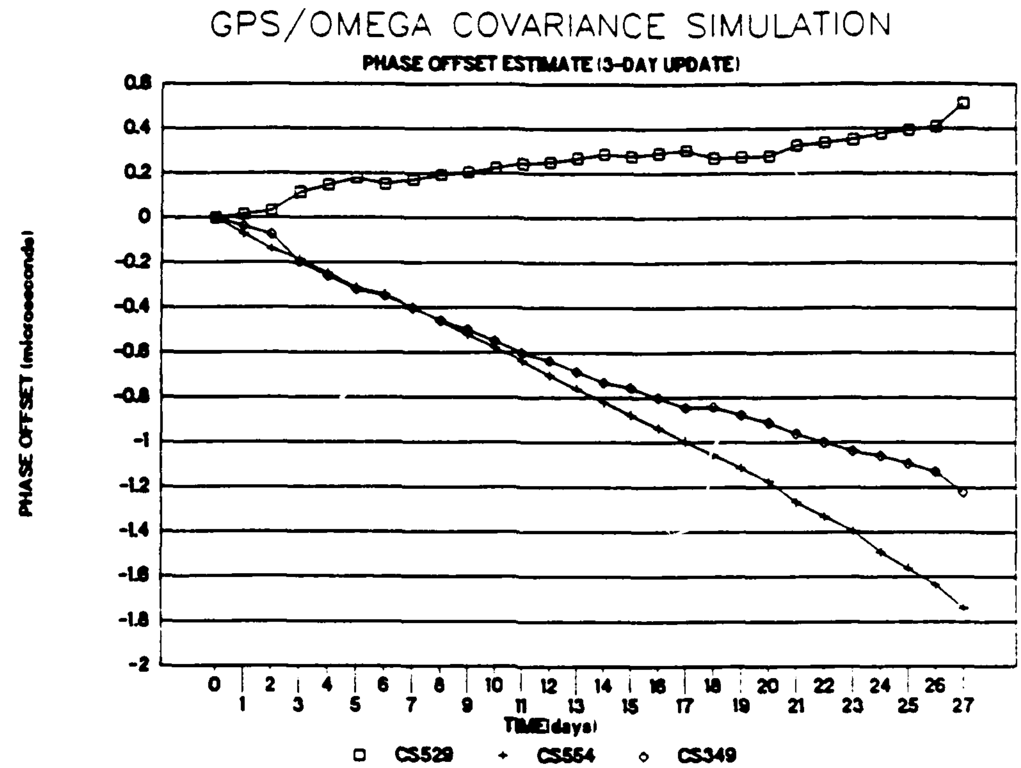


Figure 3.4-2a Phase Offset Estimate (3 Day Update)

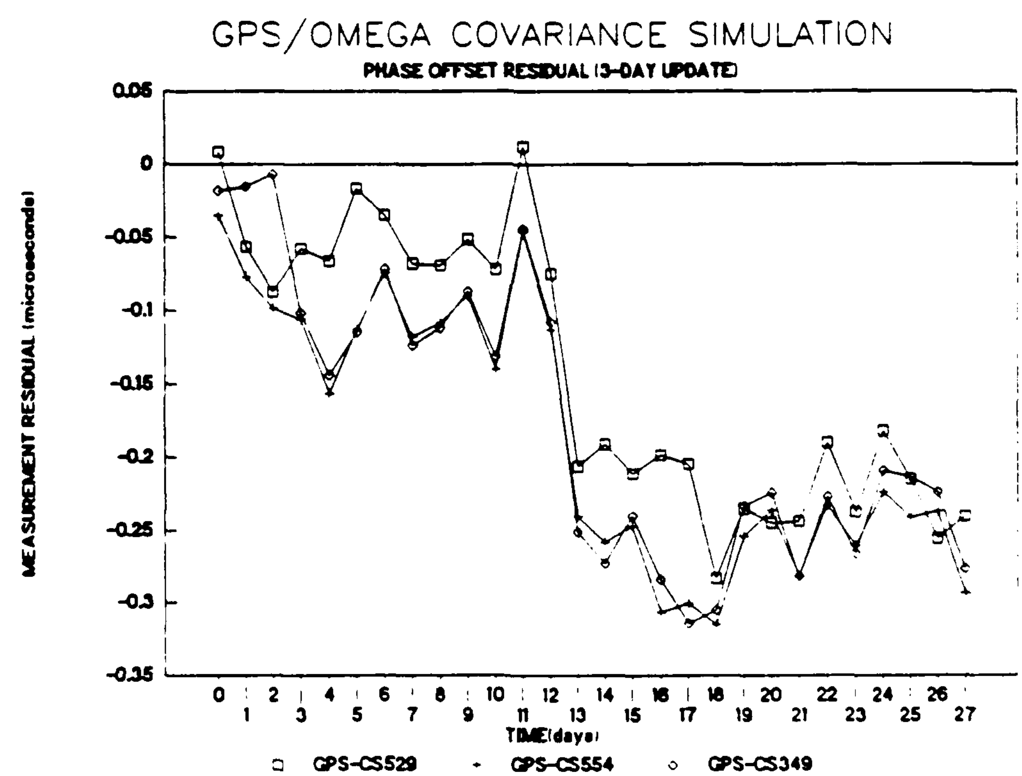


Figure 3.4-2b Phase Offset Residual: GPS-CS529, GPS-CS554, GPS-CS349 (3 Day Update)

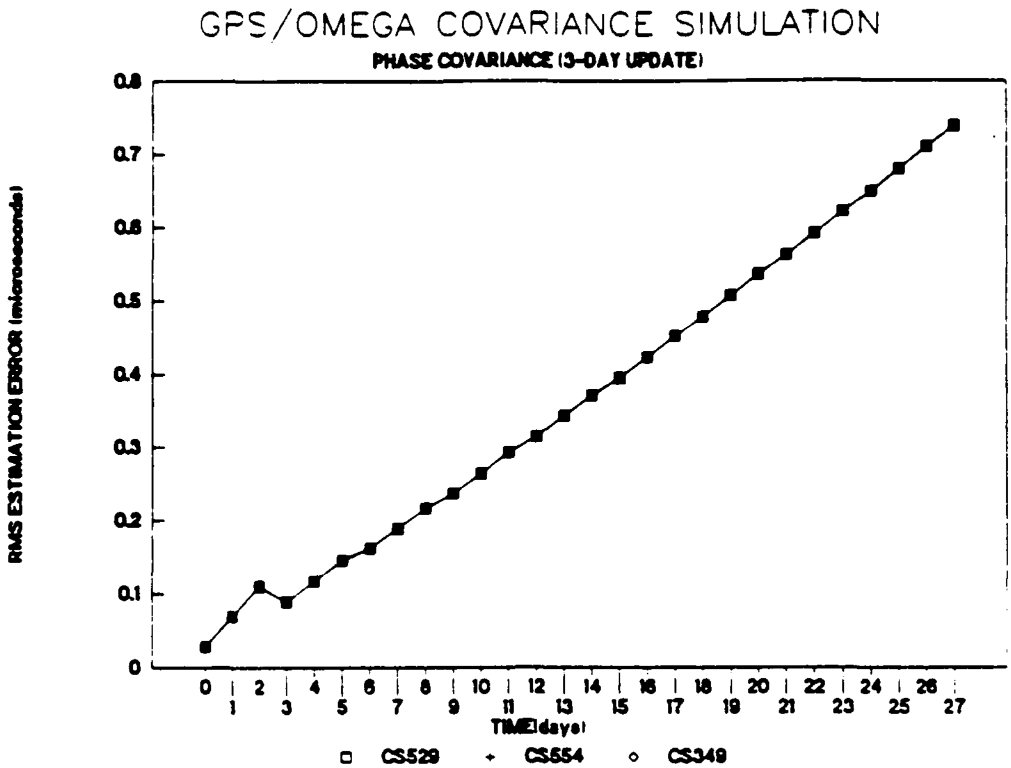


Figure 3.4-2c Phase Covariance (3 Day Update)

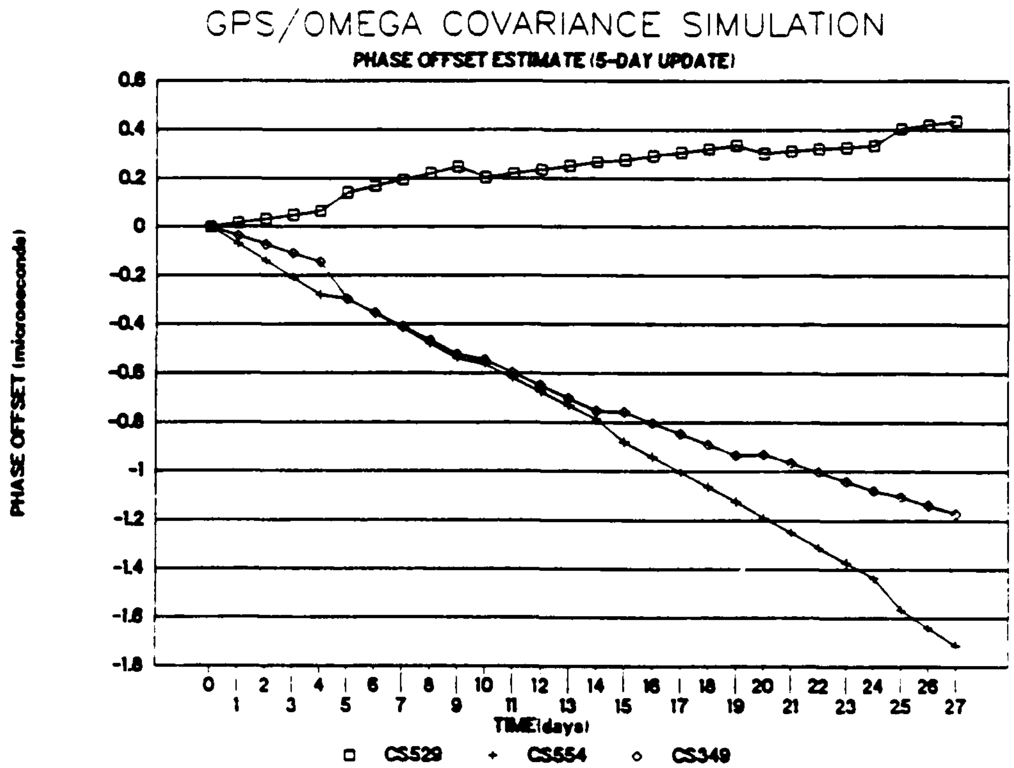


Figure 3.4-3a Phase Offset Estimate (5 Day Update)

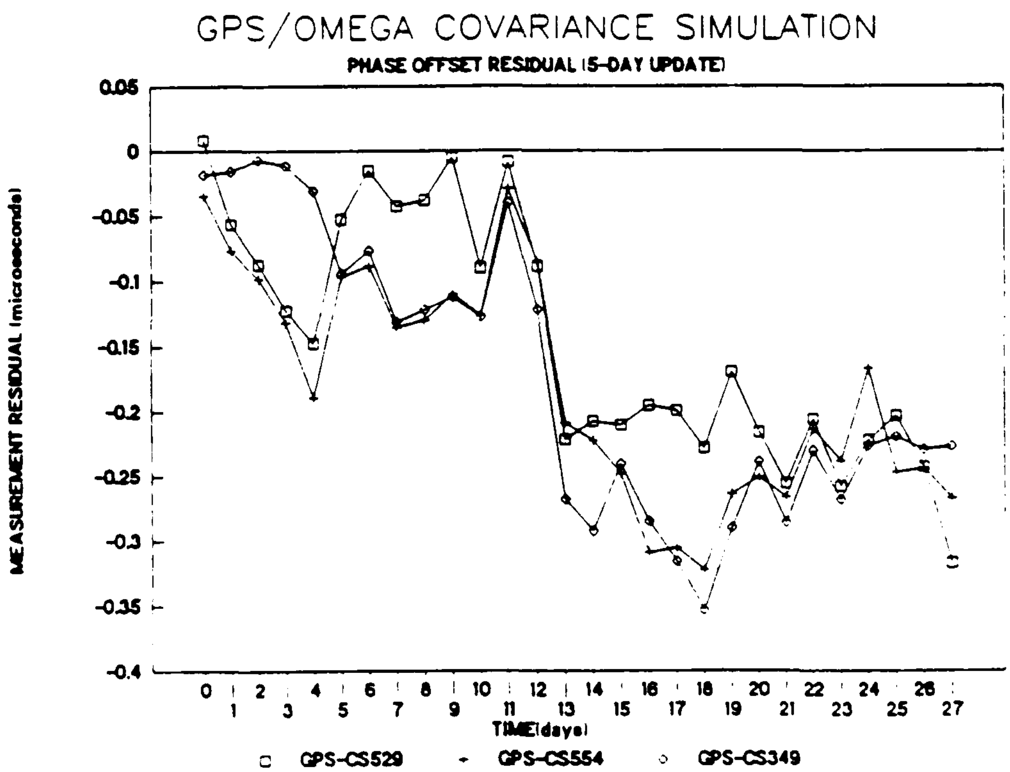


Figure 3.4-3b Phase Offset Residual: GPS-CS529, GPS-CS554, GPS-CS349 (5 Day Update)

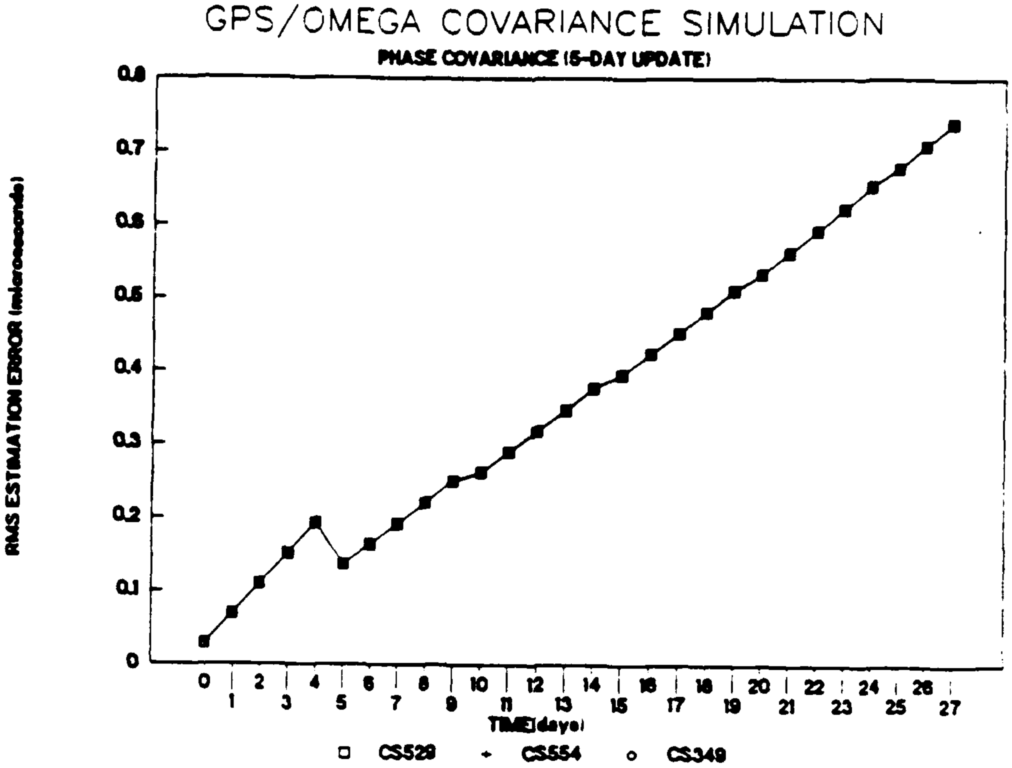


Figure 3.4-3c Phase Covariance (5 Day Update)

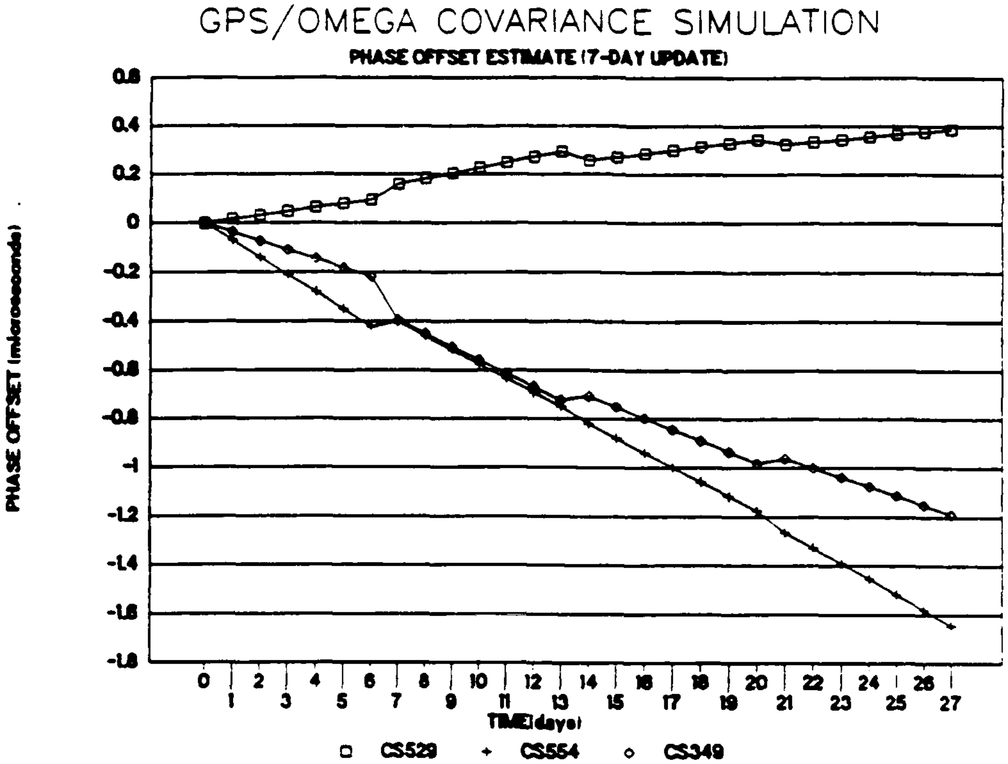


Figure 3.4-4a Phase Offset Estimate (7 Day Update)

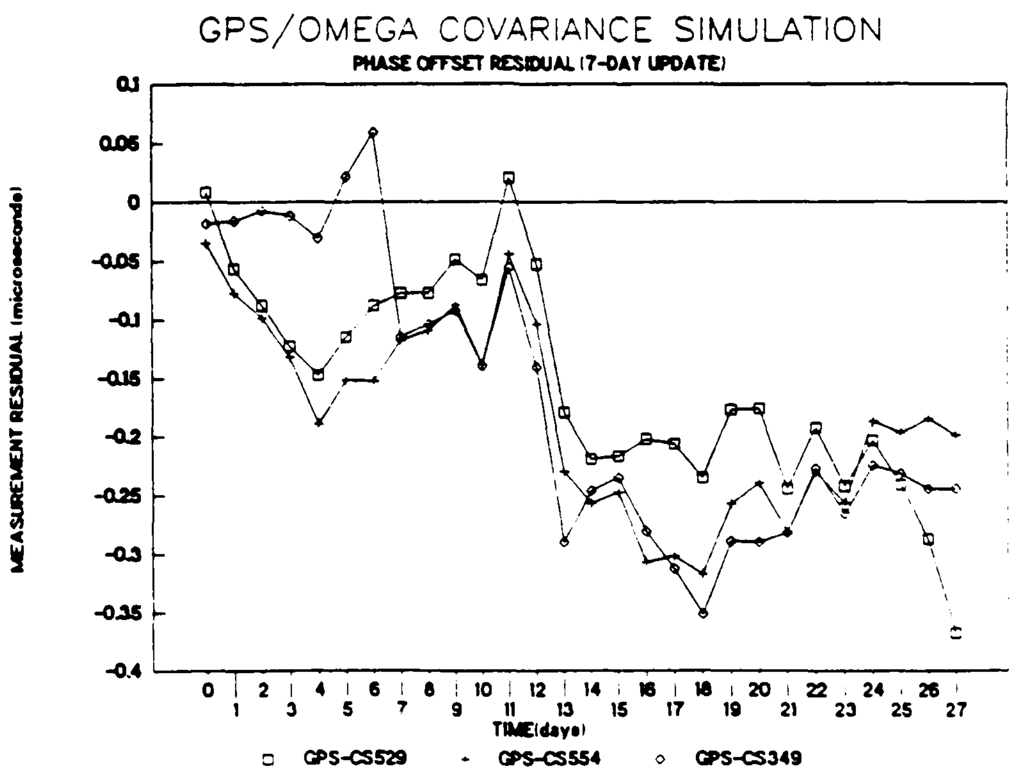


Figure 3.4-4b Phase Offset Residual: GPS-CS529, GPS-CS554, GPS-CS349 (7 Day Update)

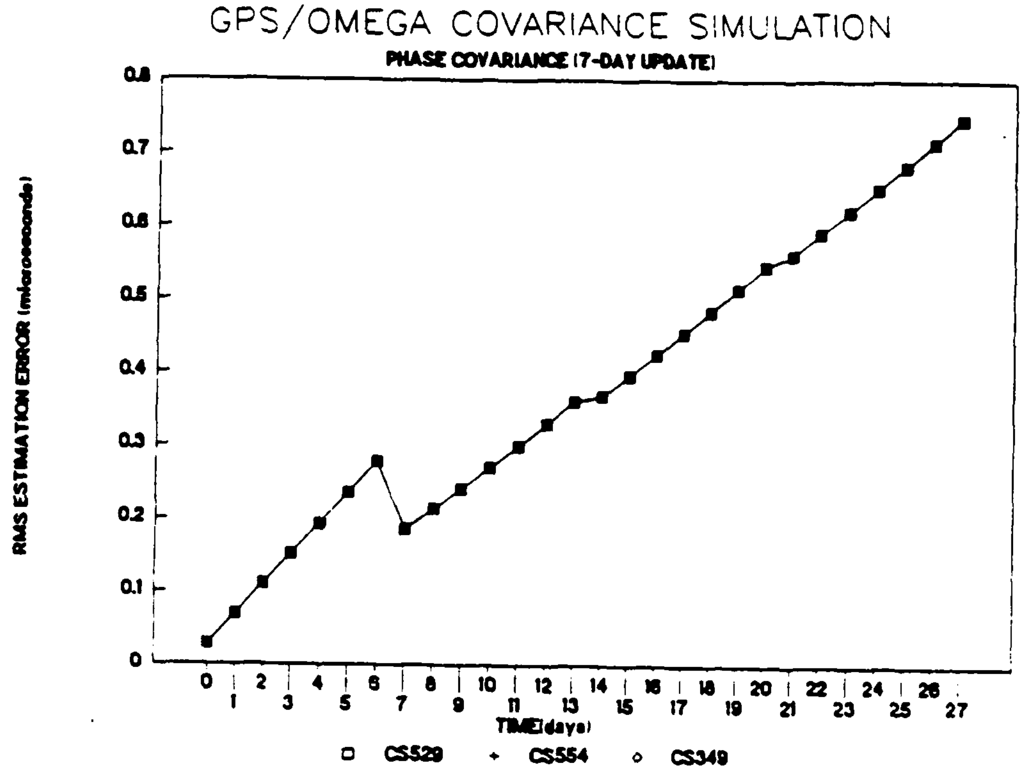


Figure 3.4-4c Phase Covariance (7 Day Update)

3.5 CONFIGURATION V

Three types of plots were generated for this configuration. They are presented in the following order:

a) Phase Offset Estimate

b) Phase Offset Residual: GPS-CS529, GPS-CS554

c) Phase Covariance

This configuration was implemented by the following event: CLK1. This event identifies CS529-CS554 measurement. The remainder of this section contains plots as described above.

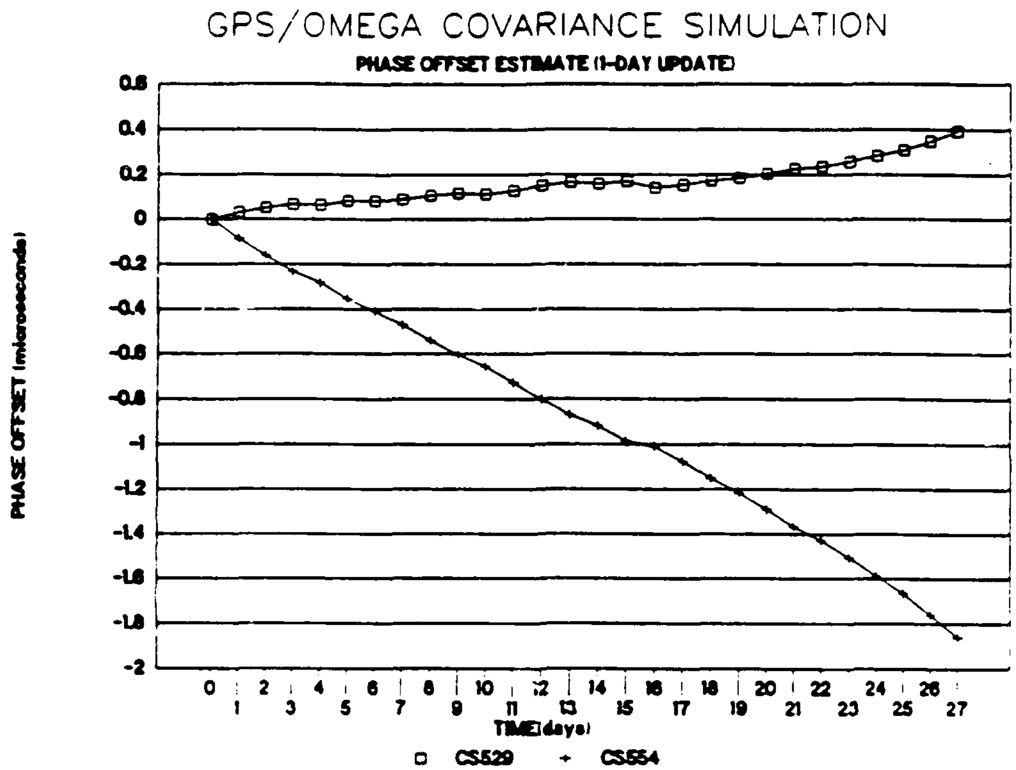


Figure 3.5-1a Phase Offset Estimate (1 Day Update)

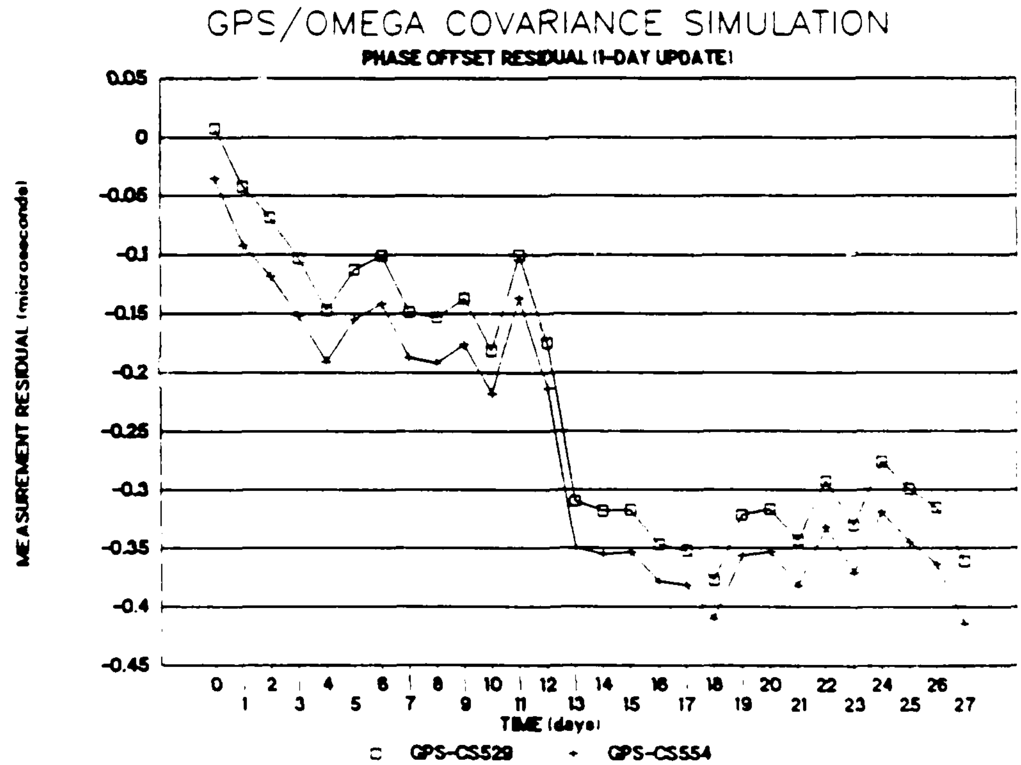


Figure 3.5-1b Phase Offset Residual: GPS-CS529, GPS-CS554 (1 Day Update)

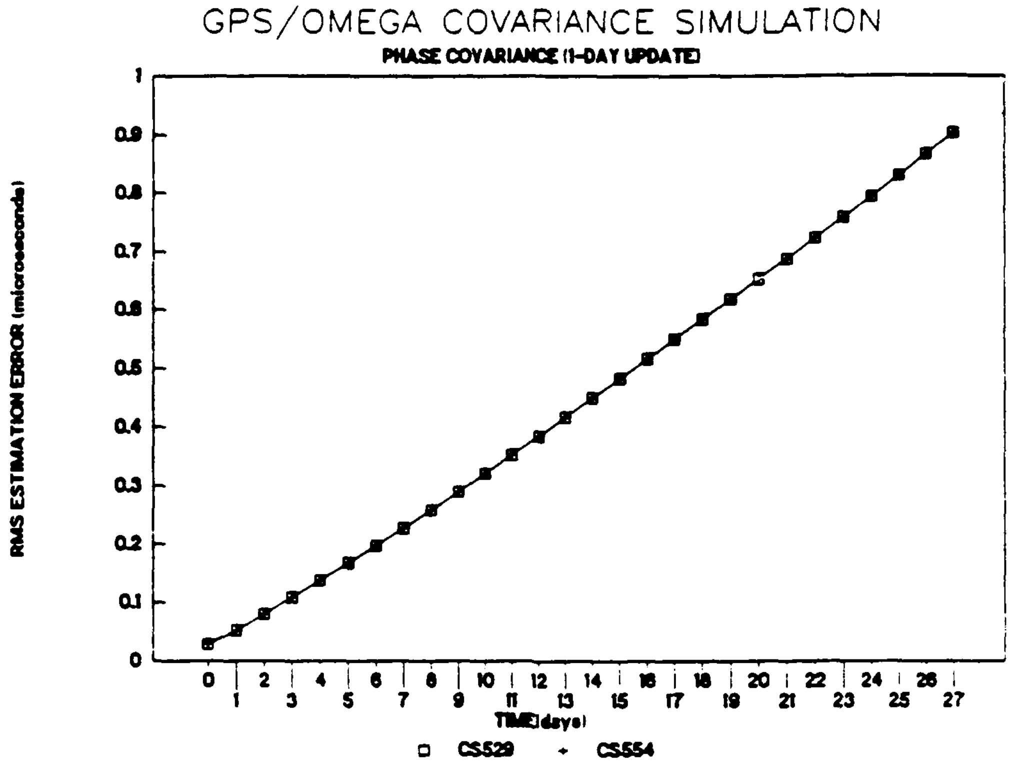


Figure 3.5-1c Phase Covariance (1 Day Update)

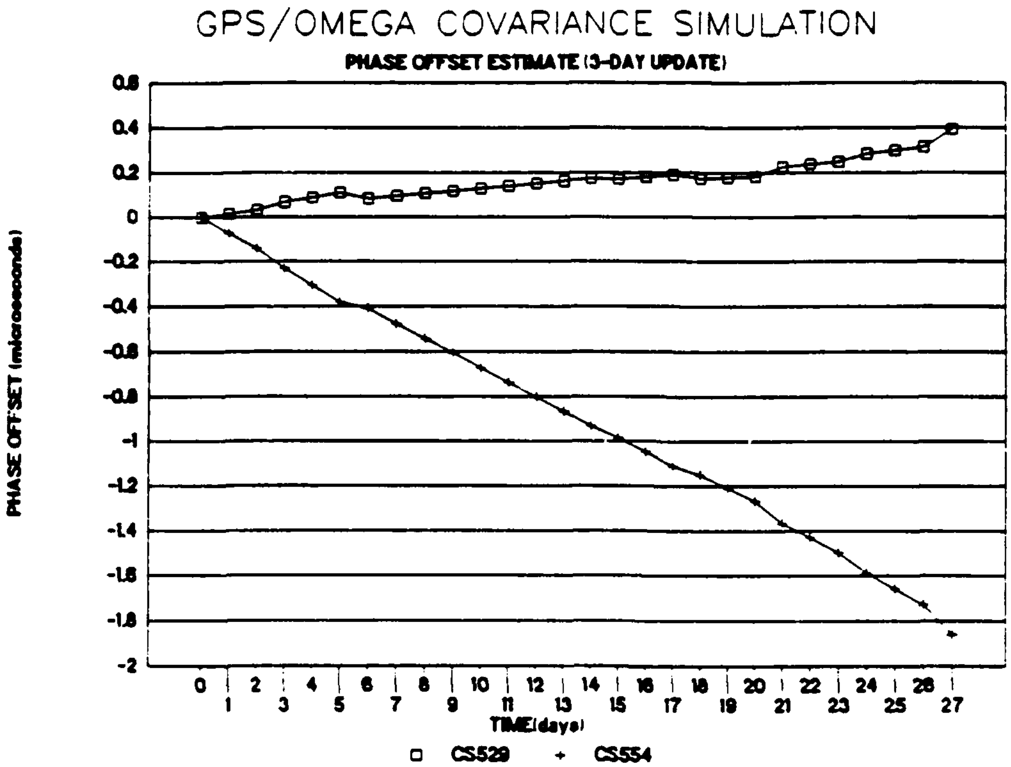


Figure 3.5-2a Phase Offset Estimate (3 Day Update)

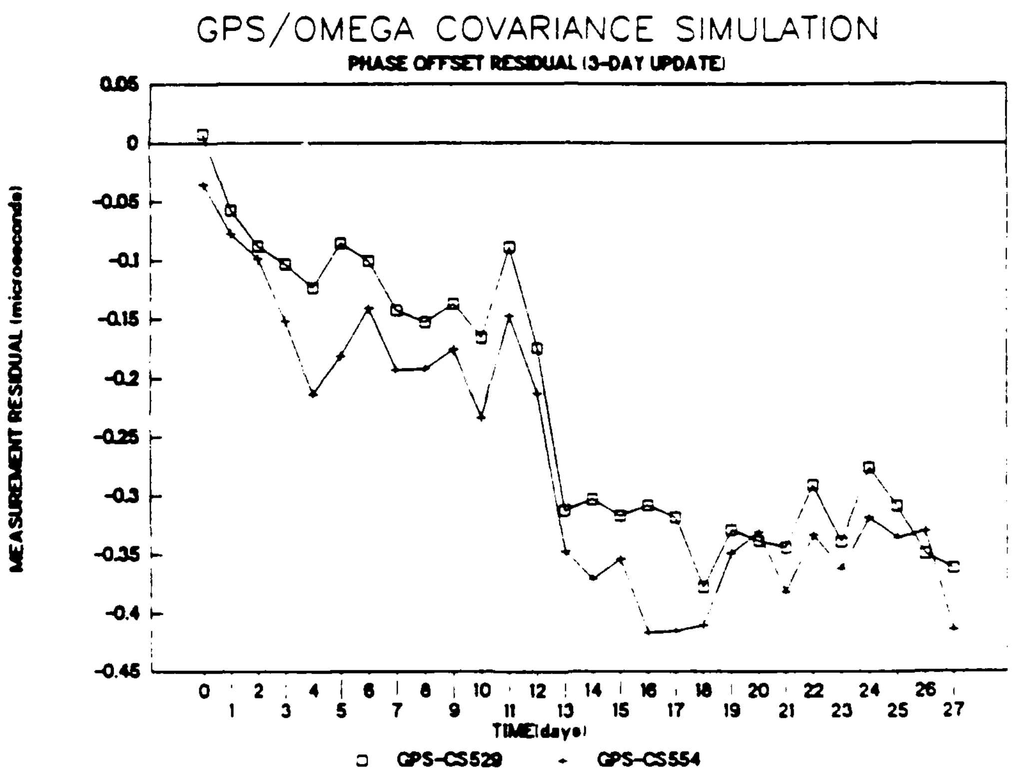


Figure 3.5-2b Phase Offset Residual: GPS-CS529, GPS-CS554 (3 Day Update)

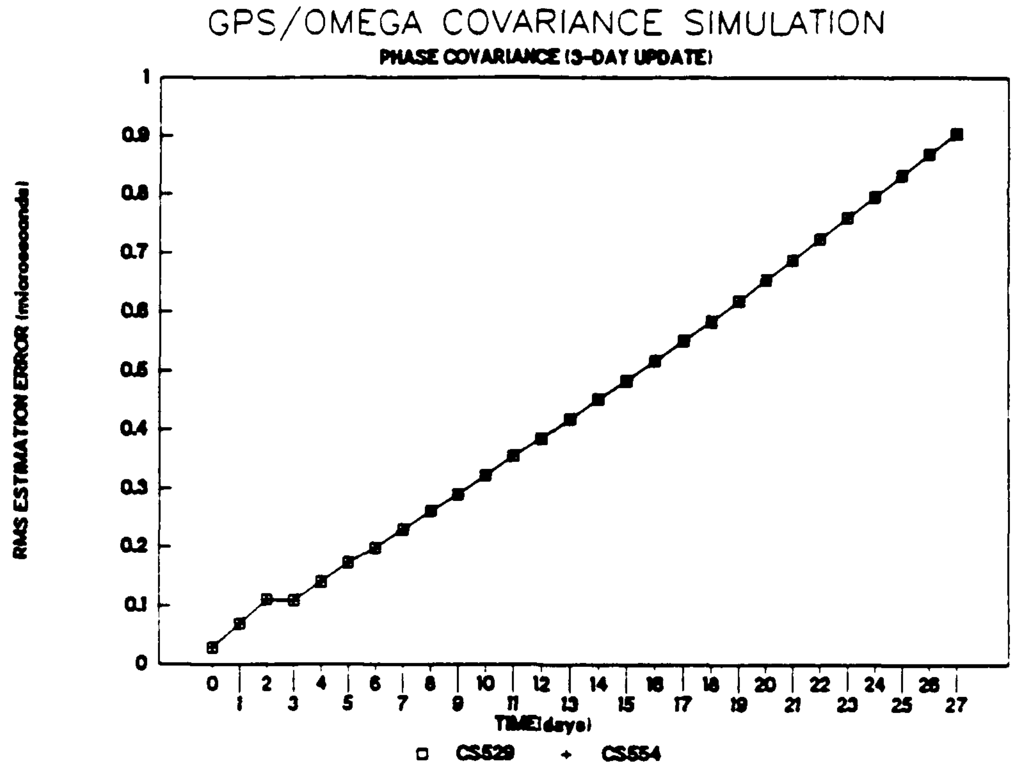


Figure 3.5-2c Phase Covariance (3 Day Update)

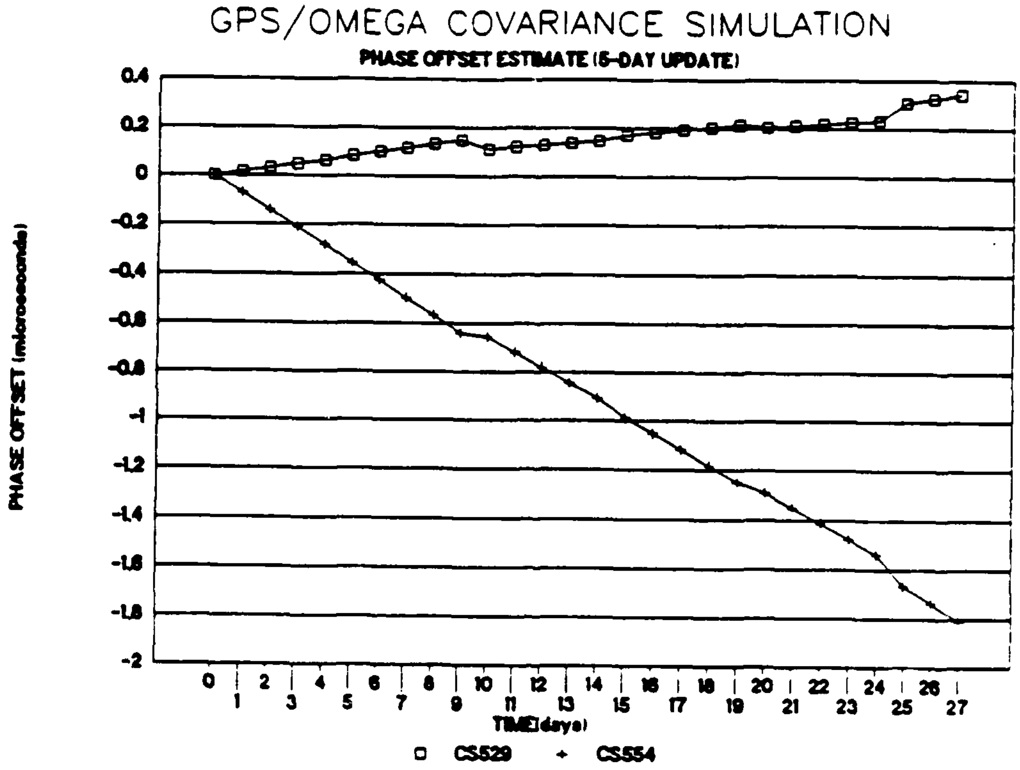


Figure 3.5-3a Phase Offset Estimate (5 Day Update)

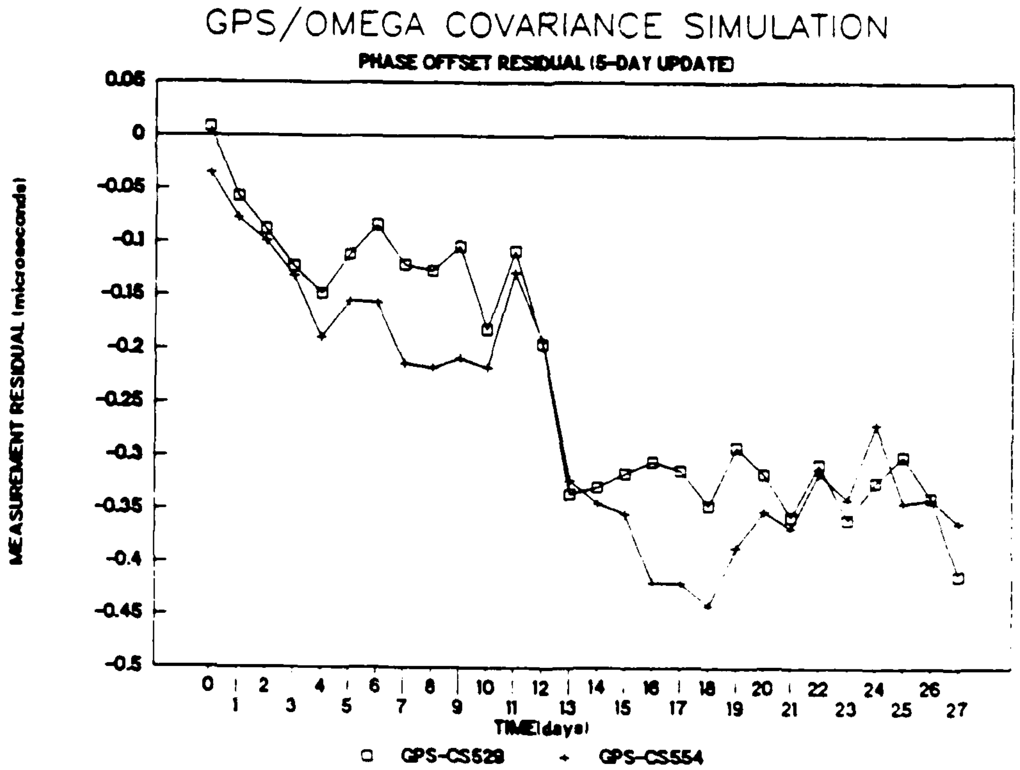


Figure 3.5-3b Phase Offset Residual: GPS-CS529, GPS-CS554 (5 Day Update)

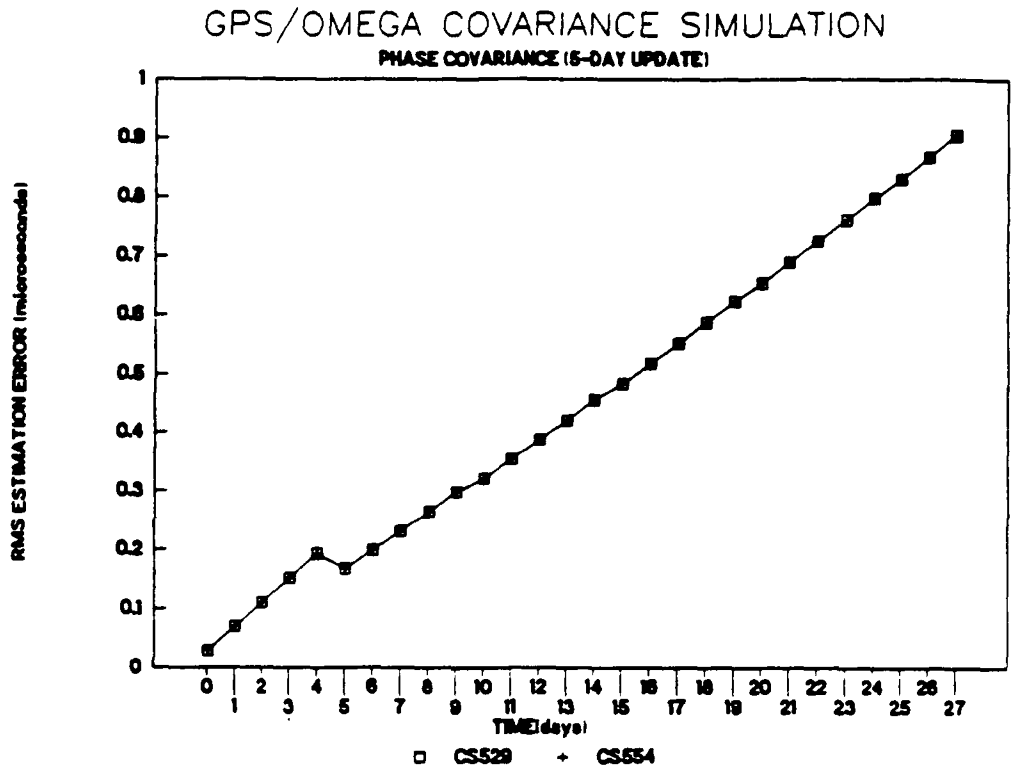


Figure 3.5-3c Phase Covariance (5 Day Update)

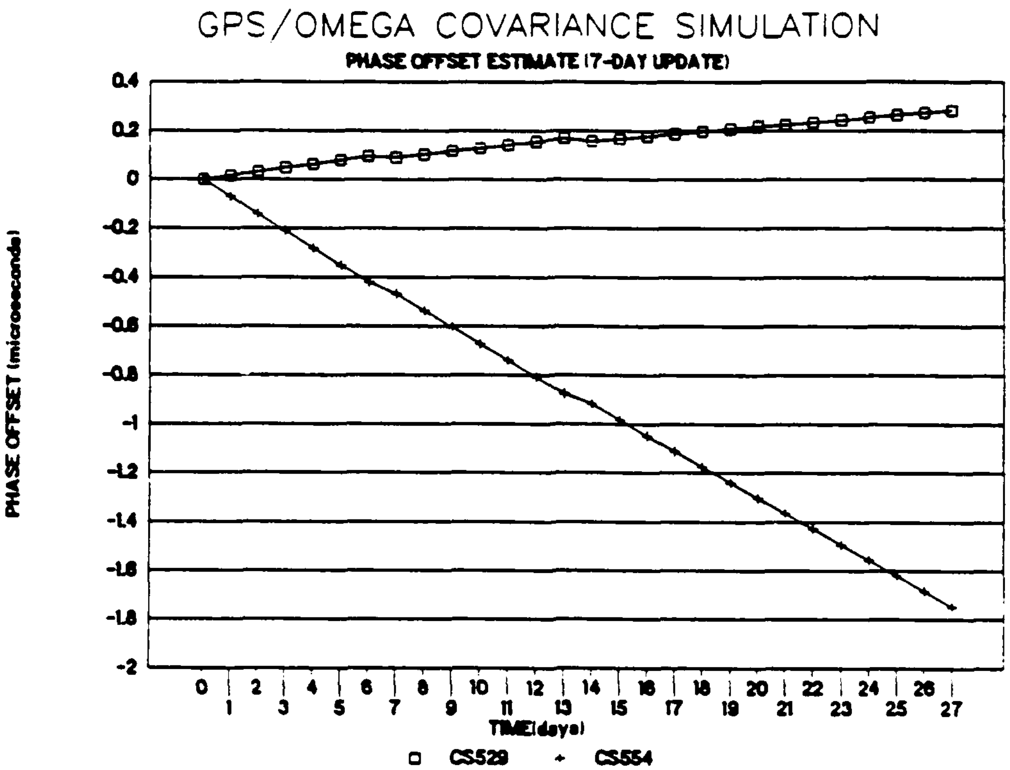


Figure 3.5-4a Phase Offset Estimate (7 Day Update)

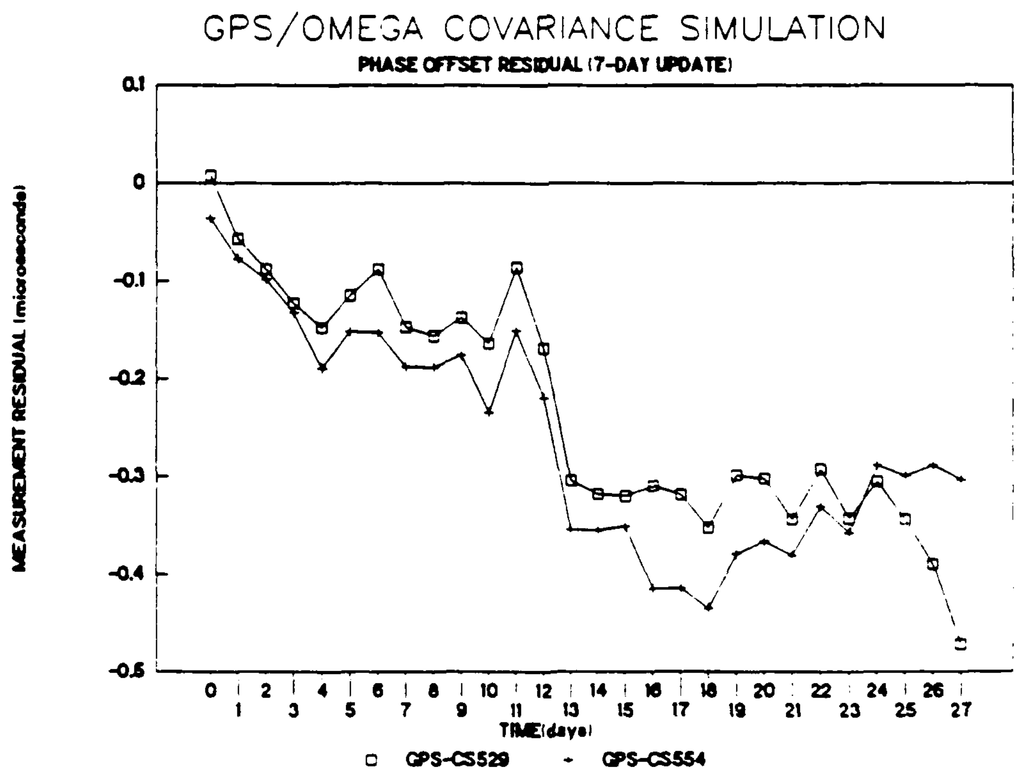


Figure 3.5-4b Phase Offset Residual: GPS-CS529, GPS-CS554 (7 Day Update)

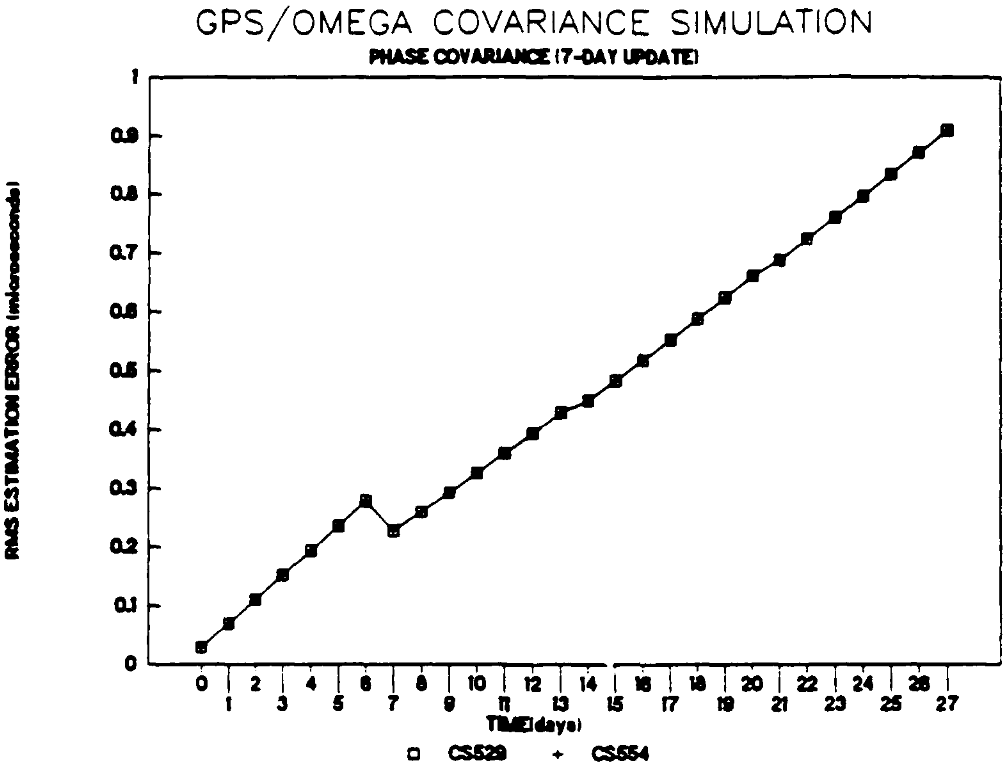


Figure 3.5-4c Phase Covariance (7 Day Update)

4. SOURCE CODE

```
      PROGRAM FILEPRC
C
C     THIS PROGRAM CONVERTS RAW INPUT DATA FILE SPECIFIED BY
C     INFILE INTO SUITABLE FORMAT (NORWAY.DAT) FOR GPSSIM (FILTER) PROGRAM
C
      CHARACTER*1  INDAT(80)
      CHARACTER*15 INFILE,OUTFILE
      REAL*8       DUMMY,GPSCS2,GPSCS3,CS1CS2,CS1CS3
      REAL*8       MJDAY,THRESH
      INTEGER      SYSTIME
C
C
C     GPSCS2 ===> GPS - CS124(CS554)
C     GPSCS3 ===> GPS - CS017 (CS349)
C     CS1CS2 ===> CS486 (CS529) - CS124 (CS554)
C     CS1CS3 ===> CS486 (CS529) - CS017 (CS349)
C
      THRESH=0.5D0
      INFILE = ' '
      OUTFILE = ' '
      WRITE(*,*)'PLEASE ENTER INPUT USNO (RDAS) RAW DATA FILENAME :'
      READ(*,101)INFILE
 101  FORMAT(A15)
      OPEN(15,FILE=INFILE,ACCESS='SEQUENTIAL',
     1     FORM='FORMATTED',STATUS='OLD',ERR=999)
      WRITE(*,*)'PLEASE ENTER OUTPUT DATA FILENAME :'
      READ(*,102)OUTFILE
 102  FORMAT(A15)
      OPEN(16,FILE=OUTFILE,ACCESS='SEQUENTIAL',
     1     FORM='FORMATTED',STATUS='UNKNOWN')
 10   READ(15,9000,END=100)INDAT
      IF (INDAT(1).EQ.'-'.AND.INDAT(2).EQ.'-') THEN
        READ(15,*)MJDAY
        READ(15,*)SYSTIME
        IF(MOD(SYSTIME,100).NE.0) GOTO 10
        MJDAY=DINT(MJDAY)
        WRITE(16,105)MJDAY,SYSTIME
 105    FORMAT(1X,F10.1,3X,I7)
        READ(15,*)GPSCS2
        READ(15,*)GPSCS3
        IF (GPSCS2.GE.THRESH) THEN
          GPSCS2=10.0D0**6*(GPSCS2-1.0D0)
        ELSE
          GPSCS2=10.0D0**6*GPSCS2
        END IF
        IF (GPSCS3.GE.THRESH) THEN
          GPSCS3=10.0D0**6*(GPSCS3-1.0D0)
        ELSE
          GPSCS3=10.0D0**6*GPSCS3
        END IF
        WRITE(16,*)GPSCS2,GPSCS3
        READ(15,*)DUMMY
        READ(15,*)DUMMY
        READ(15,*)CS1CS2
        READ(15,*)CS1CS3
        IF (CS1CS2.GE.THRESH) THEN
          CS1CS2=10.0D0**6*(CS1CS2-1.0D0)
        ELSE
```

```
          CS1CS2=10.0D0**6*CS1CS2
        END IF
        IF (CS1CS3.GE.THRESH) THEN
          CS1CS3=10.0D0**6*(CS1CS3-1.0D0)
        ELSE
          CS1CS3=10.0D0**6*CS1CS3
        END IF
        WRITE(16,*)CS1CS2,CS1CS3
      END IF
      GOTO 10
9000  FORMAT(80A1)
100   WRITE(*,9010) OUTFILE
9010  FORMAT(' STOPPED PROCESSING ',A15,' FILE')
      CLOSE(15)
      CLOSE(16)
      STOP
999   WRITE(*,9020) INFILE
9020  FORMAT(' ERROR OPENING USNO DATA INPUT FILE (',A15,')')
      WRITE(*,*) 'PLEASE CHECK FILENAME AND TRY AGAIN'
      END
```

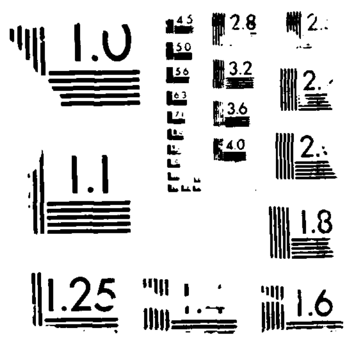
```
CCC$NOFLOATCALLS
      PROGRAM GPSSIM
C WRITTEN LBS 3/5/89
C
C
C THIS PROGRAM IS A COVARIANCE SIMULATION OF CESIUM CLOCK
C STABILITY STUDY
C
C
      REAL*8 TIME,DT,P(10,10),H(10),R,F(10,10),PHI(10,10),
     *     Q(10,10),QC(10,10),K(10),X(10),W1(10,10),
     *     W2(10,10),WT(10,10),PHASE(3),FREQ(3),CALTIME(3),
     *     MEASTIME(3),PERIOD(3),FJUMP(3),SIGGPS,SIGCLK(3)
C
      CHARACTER*5 CC
      CHARACTER*15 FILE1,FILE2
C
C
      COMMON/CLKMOT/PHASE,FREQ
      COMMON/CLKPRM/FJUMP,PERIOD
      COMMON/MEASIG/SIGGPS,SIGCLK
C
      N=6
      LSW=0
      FILE1=' '
      FILE2=' '
C
      OPEN(6,FILE='PROC.OUT',STATUS='UNKNOWN')
      WRITE(6,2)
    2 FORMAT(1X,'*** START OF PROGRAM GPSSIM***')
C
      WRITE(*,*)'PLEASE ENTER RAW MEASUREMENT DATA FILE'
      READ(*,11)FILE2
C
      WRITE(*,*)'PLEASE ENTER NAME FOR LOTUS OUTPUT FILE'
      READ(*,11)FILE1
 11   FORMAT(A15)
      OPEN(10,FILE='PARM.IN',ACCESS='SEQUENTIAL',
     1        FORM='FORMATTED',STATUS='OLD',ERR=999)
      OPEN(20,FILE=FILE1,ACCESS='SEQUENTIAL',
     1        FORM='FORMATTED',STATUS='UNKNOWN')
      READ(10,*) CC,(PHASE(I),FREQ(I),I=1,3)
      WRITE(6 *) 'INITIAL CLOCK ERROR ESTIMATES'
C
      WRITE(6,*) (PHASE(I),FREQ(I),I=1,3)
C
C DEFAULT VALUES
C
      TIME=0.
      DT=0.
      DO 20 I=1,10
        H(I)=0.0
        K(I)=0.0
        X(I)=0.0
        DO 10 J=1,10
          P(I,J)=0.
          F(I,J)=0.
          PHI(I,J)=0.
```

```
          Q(I,J)=0.
          QC(I,J)=0.
          W1(I,J)=0.
   10     CONTINUE
   20   CONTINUE
C
C
C        SET INITIAL CLOCK ESTIMATES
C
        DO 30 I=1,N/2
          X(2*I-1) = PHASE(I)
          X(2*I) = FREQ(I)
   30   CONTINUE
C
C
        READ(10,*) CC,(MEASTIME(I),I=1,N/2)
        WRITE(6,*) 'SAMPLING FREQ'
        WRITE(6,*) (MEASTIME(I),I=1,N/2)
C
        READ(10,*) CC,(P(I,I),I=1,N)
C
        WRITE(6,*) 'INITIAL COVARIANCE'
C
c        DO 40 I=1,N/2
c          P(2*I-1,2*I-1) = P(2*I-1,2*I-1)+
c     +                     P(2*I,2*I)
c   40  CONTINUE
        WRITE(6,*)(P(I,I),I=1,N)
C
C
C READ CLOCK ERROR MODEL PARAMETERS:
C              FREQUENCY JUMP MAGNITUDE
C              JUMP INTERVAL
C
        READ(10,*) CC,(FJUMP(I),PERIOD(I),I=1,N/2)
CC  IF NECESSARY FREQUENCY MAGNITUDE JUMP IS ADJUSTED
CC  TO FIT THE VALUE OF 0.0055 uSEC/DAY (RMS), BY MAKING A
CC  FJUMP = 0.03 uSEC/DAY IN PARM.IN FILE
C
C CALCULATE PROCESS NOISE
C
C
        READ(10,*) CC, (Q(I,I),I=1,N)
        DO 50 I=1,N/2
          Q(2*I,2*I) = FJUMP(I)**2/(PERIOD(I)/MEASTIME(I))
   50   CONTINUE
C
        WRITE(6,*) 'PROCESS NOISE'
C
        WRITE(6,*)(Q(I,I),I=1,N)
C
C
        READ(10,*) CC,SIGGPS,(SIGCLK(I),I=1,N/2)
        WRITE(6,*) 'MEASUREMENT VARIANCE'
C
C       CALCULATE MEASUREMENT VARIANCE
C
        SIGGPS = SIGGPS**2
```

```
      DO 60 I=1,N/2
        SIGCLK(I) = SIGCLK(I)**2
   60 CONTINUE
C
      WRITE(6,*) SIGGPS,(SIGCLK(I),I=1,N/2)
C
C RUN KALMAN FILTER
C
C
      CALL KALMAN(TIME,DT,P,H,R,K,F,PHI,QC,Q,N,W1,W2,WT,N,X,FILE2)
      CLOSE(6)
      CLOSE(10)
      CLOSE(20)
C
C*****************END MAIN GPSSIM***********************
C
      STOP
 998  WRITE(6,*) 'ERROR OPENING RAW TIMING DATA FILE'
 999  WRITE(6,*) 'ERROR OPENING PARM.IN FILE'
      END
C
C
      SUBROUTINE GETHR(MJDAY,TIME,H,R,N,MOD2,MOD3,PARMS,MEAZ,W4,
     1                 FILE2)
C
C THIS SUBROUTINE COMPUTES THE H,R MATRICES FOR AN UPDATE
C PLUS IT READS THE DATA FILE FOR TIMING MEASUREMENTS
C
      CHARACTER*15 FILE2
      REAL*8 H(10),R,MEAZ,TIME,MJDAY,Z(5),W4(10)
C
C
      INTEGER MOD2,MOD3,I1,I2,K1,K2,PARMS(80)
      INTEGER SYSTIME
C
      WRITE(6,*) 'NOW IN GETHR'
      WRITE(6,'(A4)') MOD2
C
C INITIALIZE H TO ZERO
C
      DO 10 I=1,10
        H(I)=0.0
   10 CONTINUE
C
C
      IF(MOD2.EQ.'GPS1') CALL HGPS1(H,R)
      IF(MOD2.EQ.'GPS2') CALL HGPS2(H,R)
      IF(MOD2.EQ.'GPS3') CALL HGPS3(H,R)
      IF(MOD2.EQ.'CLK1') CALL HCLK1(H,R)
      IF(MOD2.EQ.'CLK2') CALL HCLK2(H,R)
C
      CALL KFGETZ(MJDAY,TIME,SYSTIME,Z,W4,FILE2)
C
      IF(MOD2.EQ.'GPS1') MEAZ=Z(1)
      IF(MOD2.EQ.'GPS2') MEAZ=Z(2)
      IF(MOD2.EQ.'GPS3') MEAZ=Z(3)
      IF(MOD2.EQ.'CLK1') MEAZ=Z(4)
      IF(MOD2.EQ.'CLK2') MEAZ=Z(5)
```

AD-A223 307 ANALYSIS OF GPS TIMING DATA IN SUPPORT OF OMEGA SYSTEM 3/3
SYNCHRONIZATION: A..(U) SYNETICS CORP WAKEFIELD MA
G NOSEWORTHY ET AL. APR 90 J-191-6 USCG-ONSCEN-02-90
UNCLASSIFIED DTCG23-86-A-20022 F/G 17/7 NL

END
FILMED
10 90
DTIC


1.0
1.1
1.25
1.4
1.6
1.8
2.8
3.2
3.6
4.0

```
C
      WRITE(6,*)' MEAS DAY:',MJDAY,' MEAS TIME=',SYSTIME,
     1           ' MEAS= ', MEAZ
      RETURN
C
      END
C
C*******************END SUBROUTINE GETHR************************
C
      SUBROUTINE KFGETZ(MJDAY,TIME,SYSTIME,Z,W4,FILE2)
C
C     SUBROUTINE TO READ AND INTERPRET THE EVENT TABLE.
C
C
      INTEGER SYSTIME,DUM1,LCOUNT
      REAL*4 ZTIME,DUM2,DUM3
      REAL*8 Z(5),TIME,SAVDT,THRESH,MJDAY,W4(10)
      REAL*8 GPSCS2,GPSCS3,CS1CS2,CS1CS3
      CHARACTER*15 FILE2
C
      THRESH = 0.5D0
      WRITE(6,*) ' IN KFGETZ SUBROUTINE'
      OPEN(22,FILE=FILE2,ACCESS='SEQUENTIAL',
     1     FORM='FORMATTED',STATUS='OLD',ERR=999)

CCC      LCOUNT = IDINT(TIME)*24
      LCOUNT = TIME*24.0D0
      DO 10 I=1,LCOUNT
          READ(22,*)DUM2,DUM1
          READ(22,*)DUM2,DUM2
          READ(22,*)DUM3,DUM3
 10   CONTINUE
      READ(22,*)MJDAY,SYSTIME
      READ(22,*)GPSCS2,GPSCS3
      READ(22,*)CS1CS2,CS1CS3
C
       Z(1) = GPSCS2 - CS1CS2
       Z(2) = GPSCS2
       Z(3) = GPSCS3
       Z(4) = CS1CS2
       Z(5) = CS1CS3
C
       DO 20 I=1,5
         W4(I)=Z(I)
 20    CONTINUE

C
      CLOSE(22)
C
      RETURN
C
C********************END SUBROUTINE KFGETZ**************************
C
 999  WRITE(99,*)' WARNING :: ERROR OPENING NORWAY.DAT FILE'
      RETURN
      END
C
      SUBROUTINE FRTO(PARMS,I1,I2,K1,K2)
```

```
C
C THIS SUBROUTINE FINDS THE 'FROM' AND 'TO' VARIABLES IN UPDT
C
C
        CHARACTER CPARMS(80),FROM,TO
       INTEGER I1,I2,K1,K2,ISTART,ILOC,PARMS(80)
C
       FROM='F'
       TO='T'
       ISTART=1
       ILOC=0
C
CFIND FIRST FROM INTEGER AND PUT IN I1 VARIABLE
C
C
C THIS CONVERTS PARMS AS INTEGER TO CHARACTER (I HOPE)
C
        DO 5 I=1,80
        CPARMS(I) = CHAR(PARMS(I))
    5  CONTINUE
C
C
C
       CALL SEARCH(FROM,CPARMS,ISTART,I1,ILOC)
       IF(ILOC.EQ.0) GO TO 10
C
CNOW GET I2
C
       FROM=','
       ISTART=1
       ILOC=0
       CALL SEARCH(FROM,CPARMS,ISTART,I2,ILOC)
C
C GET TO VARIABLE
C
       ISTART=1
       ILOC=0
       CALL SEARCH(TO,CPARMS,ISTART,K1,ILOC)
C
C GET NEXT ANTENNA
C
       TO='+'
       ISTART=1
       ILOC=0
       CALL SEARCH(TO,CPARMS,ISTART,K2,ILOC)
C
       WRITE(6,*) 'SAT. AND ANT. FOR THIS MEAS.'
       WRITE(6,'(4(1X,I2))') I1,I2,K1,K2
C
       RETURN
C
   10  WRITE(6,100)
  100  FORMAT(1X,'    PARM CARD FORMAT ERROR IN UPDT')
       RETURN
C
       END
C
C*****************END OF FRTO*******************************
```

```
C
      SUBROUTINE SEARCH(CHAR,STRING,ISTART,IVAR,ILOC)
C
C
C  THIS ROUTINE SEARCHES 'STRING' FOR 'CHAR' STARTING AT
C ISTART.  IT THEN SEARCHES FOR THE NEXT EQUAL SIGN ANS
C SKIPS UP TO FIVE CHARACTERS TO FIND THE INTEGER AND PUT IT
C IN IVAR. IF CHAR OF EQ NOT FOUND, THEN ILOC=0
C
      CHARACTER*1 STRING(80),EQ,CHAR
      INTEGER ISTART,IVAR,ILOC,INDEX
C
C
      EQ='='
C
C  FIND 'CHAR' IN 'STRING'
C
      CALL FINDC(CHAR,STRING,ISTART,ILOC)
      IF(ILOC.EQ.0) RETURN
C
      ISTART=ILOC
      ILOC=0
C
C  FIND EQ SIGN
C
       CALL FINDC(EQ,STRING,ISTART,ILOC)
       IF(ILOC.EQ.0) RETURN
C
C SEARCH UP TO FIVE SPACES FOR NONBLANK CHAR
C
       DO 10 INDEX =1,5
         IF(STRING(ILOC+INDEX).NE.' ') GO TO 20
   10  CONTINUE
C
      ILOC=0
      RETURN
C
   20 READ(STRING(ILOC+INDEX),100) IVAR
  100 FORMAT(I1)
      RETURN
C
      END
C
C******************END SEARCH****************************
C

C
     SUBROUTINE KALMAN(TIME,DT,P,H,R,K,F,PHI,QC,Q,N,W1,W2,WT,M,X,FILE2)
C
C
C    THIS SUBROUTINE DOES COVARIANCE ANALYSIS VIA KALMAN FILTERING
C
     IMPLICIT REAL*8 (A-H,P-Z)
C
C
     REAL*8 P(10,10),F(10,10),PHI(10,10),H(10),QC(10,10),Q(10,10)
     REAL*8 W1(10,10),W2(10,10),WT(10,10),X(10),W3(10),W4(10)
     REAL*8 K(10),NEWDT,EVTAB(50,8),MJDAY,DT,TIME
```

```
      INTEGER EVENT,PARMS(80),MOD1,MOD2,MOD3,PRMTAB(50,80),N
      REAL*4 SEVTAB(50,8),STIME,SSDT,SNEWDT
      CHARACTER*15 FILE2
C
C
C   SET UP EVENT TABLE
C
      CALL KFTABL(SEVTAB,PRMTAB)
      DO 3 I=50
      DO 3 J=8
        EVTAB(I,J) = DBLE(SEVTAB(I,J))
    3 CONTINUE
C
C
C   SET INITIAL TIME AND DT
      TIME=0.0D0
      DT=EVTAB(21,7)
C     READ CONTROL CARD
       STIME = 0.0
       SSDT = SEVTAB(21,7)
C
 1000  CALL KFREAD(STIME,SSDT,SNEWDT,SEVTAB,PRMTAB,EVENT,
     1             MOD1,MOD2,MOD3,PARMS)
C
       DT = DBLE(SSDT)
       NEWDT = DBLE(SNEWDT)
C
C     END OF FILTER RUN
C
      IF (EVENT.EQ.'STOP') GOTO 9999
C
C     PROPAGATE
C
      IF (EVENT.EQ.'PROP') CALL KFPROP(MJDAY,TIME,DT,NEWDT,MOD1,
     1    MOD2,MOD3,N,P,H,F,PHI,QC,Q,PARMS,W1,W2,W3,W4,X,FILE2)
       IF(EVENT.EQ.'PROP') STIME = SNGL(TIME)
C
C     OR UPDATE
C
      IF (EVENT.EQ.'UPDT')CALL KFUPDT(MJDAY,TIME MOD1,MOD2,MOD3,N,P,H,
     1    R,K,PARMS,W1,W2,W3,W4,X,FILE2)
C
C     OR PRINT
C
C      IF (EVENT.EQ.'PRNT') CALL KFPRNT(TIME,MOD1,MOD2,MOD3,P,F,PHI,H,R,
C     1      K,QC,Q,N,PARMS,W1,X)
C
C   OR USER DEFINED
      IF (EVENT .EQ. 'USER') CALL KFUSER(MJDAY,TIME,DT,MOD1,MOD2,MOD3,
     1    P,F,PHI,Q,QC,H,K,R,WT,W1,W2,W3,W4,PARMS,M,N,X)
C
      GOTO 1000
 9999 RETURN
      END
C
C***********************END OF KALMAN ROUTINE ***************************
C
      SUBROUTINE ABADD(A,B,M,N,C)
```

```
C
C
C
C     SUBROUTINE TO DO THE MATRIX ADDITION C=A+B
C     THE MATRICES A,B,C NEED NOT BE DISTINCT
C
       IMPLICIT REAL*8 (A-H,P-Z)
C
      DIMENSION A(10,10),B(10,10),C(10,10)
C
      DO 10 J=1,N
         DO 10 I=1,M
   10       C(I,J)=A(I,J)+B(I,J)
      RETURN
      END
      SUBROUTINE ABMULT(A,B,L,M,N,C,W1)
C
C
C     SUBROUTINE TO COMPUTE THE MATRIX PRODUCT C=A'B
C     A,B,C NEED NOT BE DISTINCT.  W1 CAN NOT BE THE SAME
C     AS A OR B
C
       IMPLICIT REAL*8 (A-H,P-Z)
C
       REAL*8 A(10,10),B(10,10),C(10,10),W1(10,10)
C
      DO 20 J=1,N
         DO 20 I=1,L
            SUM=0.0D0
            DO 10 K=1,M
   10          SUM=SUM+A(I,K)*B(K,J)
   20       W1(I,J)=SUM
      DO 30 J=1,N
         DO 30 I=1,L
   30       C(I,J)=W1(I,J)
      RETURN
      END
      SUBROUTINE KFERR(TIME,CARD)
       IMPLICIT REAL*8 (A-H,P-Z)
C
C     SUBROUTINE TO STOP THE PROGRAM IN CASE OF A SERIOUS ERROR.
C
      INTEGER CARD(8)
      WRITE(6,100) TIME,(CARD(I),I=1,8)
  100   FORMAT(///,'*****  IMPROPER EVENT AT TIME= ',G10.5,
     1          '         EVENT CARD IS:  ',/,5X,8A10)
      STOP
      END
      SUBROUTINE KFHPHT(A,B,M,N,C,W1)
C
C
C     SUBROUTINE TO COMPUTE THE MATRIX PRODUCT C=A*B*TRANS(A)
C     WHERE B IS SYMMETRIC AND THE RESULT IS SYMMETRIC.
C     THE MATRICES A,B,C NEED NOT BE DISTINCT.
C
        IMPLICIT REAL*8 (A-H,P-Z)
C
      REAL*8 A(10,10),B(10,10),C(10,10),W1(10,10)
```

```
C
      DO 10 I=1,M
         DO 10 J=I,M
            TERM=0.0D0
            DO 100 K=1,N
               SUM=0.0D0
               DO 200 L=1,K
  200                  SUM=SUM+A(I,L)*B(L,K)
               IF (K.EQ.N) GOTO 100
                KP1 = K+1
               DO 300 L=KP1,N
  300                  SUM=SUM+A(I,L)*B(K,L)
  100            TERM=TERM+SUM*A(J,K)
   10        W1(I,J)=TERM
C
C     COPY W1 INTO RETURN MATRIX C
C
      DO 20 I=1,M
         DO 20 J=I,M
           C(I,J)=W1(I,J)
   20         C(J,I)=W1(I,J)
      RETURN
      END
      SUBROUTINE KFPRNT(TIME,MOD1,MOD2,MOD3,P,F,PHI,H,R,K,QC,Q,N,PARMS,
     1           W1,X)
C
C
C    SUBROUTINE TO PRINT THE DESIRED MATRIX IN IT'S DESIRED FORM.
       IMPLICIT REAL*8 (A-H,P-Z)
C
C
      REAL*8 P(10,10),F(10,10),PHI(10,10),QC(10,10),Q(10,10)
      REAL*8 H(10),W1(10,10)
      REAL*8 K(10),X(10)
      INTEGER PARMS(80),MOD1,MOD2,MOD3
C
C
      WRITE(6,100) TIME,MOD1,MOD2,(PARMS(J),J=1,80)
  100   FORMAT(//,'***  TIME= ',G10.3,2(5X,A4),1X,80A1)
C
C     DETERMINE PRINT TYPE
      IF (MOD1.EQ.'FULL') GOTO 1000
      IF (MOD1.EQ.'CORR') GOTO 2000
      IF (MOD1.EQ.'LTRI') GOTO 3000
      IF (MOD1.EQ.'PRMS') GOTO 4000
      IF (MOD1.EQ.'UDER') GOTO 5000
      IF (MOD1.EQ.'DEBG') GOTO 6000
C
C     UNDEFINED PRINT TYPE.  PRINT WARNING AND RETURN.
C
      WRITE(6,200)
  200   FORMAT(//,'*****  UNRECOGNIZED PRINT OPTION SPECIFIED  *****')
      GOTO 9999
C
C     PRINT THE FULL MATRIX
 1000 IF (MOD2.EQ.'P') CALL PRINT(P,N,N)
      IF (MOD2.EQ.'F') CALL PRINT(F,N,N)
      IF (MOD2.EQ.'X') CALL VPRINT(X,N)
```

```
      IF (MOD2.EQ.'PHI') CALL PRINT(PHI,N,N)
      IF (MOD2.EQ.'Q') CALL PRINT(Q,N,N)
      IF (MOD2.EQ.'QC') CALL PRINT(QC,N,N)
      IF (MOD2.EQ.'H') CALL VPRINT(H,N)
      IF (MOD2.EQ.'K') CALL VPRINT(K,N)
      IF (MOD2.EQ.'R') WRITE(6,1100) R
 1100    FORMAT(/,5X,G10.3)
      GOTO 9999
C
C     PRINT THE CORRELATION COEFFICIENTS
 2000      IF(MOD2.EQ.'P') GOTO 2002
 2001      WRITE(6,2101)
 2101   FORMAT(//,'*****  IMPROPER MATRIX SPECIFIED  *****')
      GOTO 9999
 2002      DO 2022 I=1,N
         DO 2012 J=1,I
 2012        W1(I,J)=P(I,J)/DSQRT(P(I,I)*P(J,J))
 2022      WRITE(6,2122) I,(W1(I,J),J=1,I)
 2122      FORMAT(//,I5,3X,10(G10.3,1X)/(8X,10(G10.3,1X)))
      GOTO 9999
C
C     PRINT THE LOWER TRIANGULAR PORTION OF THE MATRIX
 3000      GOTO 9999
C
C     PRINT THE RMS VALUES OF THE P MATRIX
 4000      IF (MOD2.NE.'P  ') GOTO 2001
           DO 4010 I=1,N
 4010   W1(1,I)=SQRT(P(I,I))
      WRITE (*,4100) (W1(1,I),I=1,N)
 4100   FORMAT(//(3X,10(1X,G10.3)))
        GOTO 9999
C
C     PRINT USER DEFINED MATRICES
 5000   GOTO 9999
CC  CALL UPRINT(TIME,MOD2,MOD3,PARMS,P,F,PHI,Q,QC,H,K,N,W1)
C
C     PRINT DEBUG MATRICES
 6000   GOTO 9999
C
 9999      RETURN
      END
      SUBROUTINE KFPROP(MJDAY,TIME,DT,NEWDT,MOD1,MOD2,MOD3,N,P,H,
     1          F,PHI,QC,Q,PARMS,W1,W2,W3,W4,X,FILE2)
C
C
C     SUBROUTINE TO DO KALMAN FILTERING COVARIANCE PROPAGATION
       IMPLICIT REAL*8 (A-H,P-Z)
C
C
      REAL*8 P(10,10),F(10,10),PHI(10,10),QC(10,10),Q(10,10)
      REAL*8 W1(10,10),W2(10,10),W3(10),H(10),MEAZ(5),W4(10)
      REAL*8 X(10),MJDAY,TIME,Z,HX
      INTEGER  MOD1,MOD2,MOD3,PARMS(80),SYSTIME,N
      REAL*8 NEWDT,OLDDT,DT
      CHARACTER*15 FILE2
      DATA OLDDT/0.0/
C
C
```

```
      WRITE(6,*)' NOW IN --- KFPROP ---'
C
C     CHECK FOR TIME VARYING SYSTEM
C
CCCC        IF (MOD1.EQ.'VARY') CALL GETFQC(TIME,DT,F,QC,N,MOD2,MOD3,PARMS)
C
C  COMPUTE NEW PHI AND Q IF NEW DT OR NEW F OR NEW QC
C
      IF ((OLDDT .NE. DT)  .OR.  (MOD1 .EQ. 'VARY'))
     1CALL PHICOM(DT,F,QC,Q,N,PHI,W1,W2)
C
C           PROPAGATE THE STATE,IF REQUESTED
C
      IF (MOD2.NE.'STAT') GOTO 30
      DO 10 I=1,N
          W1(I,1)=0.0
        DO 20 J=1,N
          W1(I,1)=W1(I,1)+PHI(I,J)*X(J)
 20     CONTINUE
 10     CONTINUE
       DO 25 I=1,N
         X(I)=W1(I,1)
 25    CONTINUE
C
C INSERTED BY ATO 4/15/85 TO SIMULATE DRIVING TERM
CCCC        IF(MOD3.EQ.'DRVN') CALL GETU(X,N,DT)
C
C
C              PROPAGATE P MATRIX
C
   30  CALL KFHPHT(PHI,P,N,N,P,W1)
       CALL ABADD(P,Q,N,N,P)
C
C   PROPAGATE CLOCK READOUT
C
CCCCC          CALL RHOCOM(TIME,DT,MOD2,MOD3,PARMS)
C
C   CALCULATE MEASUREMENT RESIDUALS AT PROPAGATE TIME
C
C
C
      CALL KFGETZ(MJDAY,TIME,SYSTIME,MEAZ,W4,FILE2)
C
      DO 47 I=1,5
        DO 45 J=1,N
          H(J) = 0.0D0
  45    CONTINUE
         IF (I.EQ.1) THEN
           H(1)=-1.0D0
         ELSE
           IF (I.EQ.2) THEN
             H(3)=-1.0D0
           ELSE
             IF (I.EQ.3) THEN
               H(5)=-1.0D0
             ELSE
               IF (I.EQ.4) THEN
                   H(1)=1.0D0
```

```
                 H(3)=-1.0D0
              ELSE
                IF (I.EQ.5) THEN
                    H(1)=1.0D0
                    H(5)=-1.0D0
                END IF
              END IF
            END IF
          END IF
        END IF
        HX=0.0D0
        DO 46 J=1,N
          HX=HX+H(J)*X(J)
   46   CONTINUE
C
        W3(I) = MEAZ(I) - HX

   47 CONTINUE
      WRITE(6,*)' MEAS DAY:',MJDAY,' MEAS TIME=',SYSTIME,
     1           ' MEAS= ', MEAZ
      WRITE(6,*)' STATE VECTOR X(I): ',X
      WRITE(6,*)' RESIDUALS: ',W3
C
C   UPDATE TIME AND DT
C
      TIME = TIME + DT
      OLDDT = DT
      DT = NEWDT
      RETURN
      END
      SUBROUTINE KFUPDT(MJDAY,TIME,MOD1,MOD2,MOD3,N,P,H,R,K,PARMS,
     1                  W1,W2,W3,W4,X,FILE2)
C
C
C     SUBROUTINE TO PERFORM THE KALMAN FILTER COVARIANCE
C     MATRIX UPDATE.
C     W3 vector contains the residuals for measurements used
C     in this run of a filter
C
      IMPLICIT REAL*8 (A-H,P-Z)
C
C
      REAL*8 P(10,10),H(10),X(10),W1(10,10),W2(10,10)
      INTEGER MOD1,MOD2,MOD3,PARMS(80),M,N
      REAL*8 K(10),MJDAY,TIME,W3(10),W4(10),Z,HX
      CHARACTER*15 FILE2
C
C
C
      WRITE(6,*)' NOW IN --- KFUPDT ---'
C     GET NEW H AND R IF NEEDED.
C
      IF (MOD1.EQ.'VARY')
     1    CALL GETHR(MJDAY,TIME,H,R,N,MOD2,MOD3,PARMS,Z,W4,FILE2)
C
C     COMPUTE THE KALMAN GAINS MATRIX, K.
C
      HPHT=0.0D0
```

```
C
      DO 20 J=1,N
        SUM=0.0D0
         DO 10 I=1,N
 10          SUM=SUM+H(I)*P(I,J)
 20       HPHT=HPHT+SUM*H(J)
C
      HPHT=HPHT+R
      DO 40 I=1,N
         SUM=0.0D0
         DO 30 J=1,N
 30          SUM=SUM+P(I,J)*H(J)
 40       K(I)=SUM/HPHT
      IF (MOD3.NE.'STAT') GOTO 49
C
C       UPDATE STATE VECTOR
C
      HX=0.0D0
      DO 47 I=1,N
         HX=HX+H(I)*X(I)
 47   CONTINUE
C
      DO 48 I=1,N
        X(I)=X(I)+K(I)*(Z-HX)
 48   CONTINUE
CC
C       CALCULATE RESIDUAL
C
      HX=0.0D0
      DO 46 I=1,N
         HX=HX+H(I)*X(I)
 46   CONTINUE
C
      IF (MOD2.EQ.'GPS1') W3(1) = Z - HX
      IF (MOD2.EQ.'GPS2') W3(2) = Z - HX
      IF (MOD2.EQ.'GPS3') W3(3) = Z - HX
      IF (MOD2.EQ.'CLK1') W3(4) = Z - HX
      IF (MOD2.EQ.'CLK2') W3(5) = Z - HX
C
 49      CONTINUE
C
C     UPDATE THE COVARIANCE MATRIX, P.
C
      DO 60 I=1,N
         DO 50 J=1,N
 50           W1(I,J)=-K(I)*H(J)
 60         W1(I,I)=W1(I,I)+1.0D0
C
      CALL KFHPHT(W1,P,N,N,P,W2)
      DO 70 I=1,N
         DO 70 J=1,N
 70        W1(I,J)=K(I)*K(J)*R
      CALL ABADD(P,W1,N,N,P)
      RETURN
      END
      SUBROUTINE PHICOM(DT,F,QC,Q,N,PHI,W1,W2)
C
C
```

```
C     SUBROUTINE TO COMPUTE PHI = EXP (F*DT)
       IMPLICIT REAL*8(A-H,P-Z)
C
C
      REAL*8 F(10,10),QC(10,10),Q(10,10),PHI(10,10)
      REAL*8 W1(10,10),W2(10,10)
      REAL*8 L1NORM,K,KFACT
      DATA DELTA,KCOUNT/1.0D-5,20/
C
C     COMPUTE THE L1 NORM OF F*DT
C
      L1NORM=0.0D0
      M=0
C
C      DO 20 J=1,N
C         TEMP = 0.0D0
C         DO 10 I=1,N
C 10          TEMP=TEMP+DABS(F(I,J))
C   20     IF (TEMP.GT.L1NORM) L1NORM=TEMP
C           L1NORM=L1NORM*DT
CC
C  CHECK TO SEE IF NORM IS ZERO
C        IF (L1NORM .LT. 1.0D-10) GOTO 25
C
C     SCALE F*DT
C
C       RLOG = (DLOG10(L1NORM))/(DLOG10(2.0D0))
C        IF (L1NORM.LT.1) M=0
C        IF (L1NORM.GE.1 .AND. L1NORM.LT.2) M=1
C        IF (L1NORM.GE.2) M=IDINT(RLOG)+1
C   25 TEMP=DT/(2.0D0**M)
C      DO 40 J=1,N
C         DO 30 I=1,N
C            PHI(I,J)=F(I,J)*TEMP
C   30         W1(I,J)=PHI(I,J)
C   40        PHI(J,J)=PHI(J,J)+1.0D0
C      L1NORM=L1NORM/(2.0D0**M)
CC
C     COMPUTE EXP(W1) BY TAYLOR
C
C      K=1.0D0
C      KFACT=1.0D0
C 1000  K=K+1.0D0
C      KFACT=KFACT*K
C      CALL ABMULT(F,W1,N,N,N,W1,W2)
C      DO 60 J=1,N
C         DO 60 I=1,N
C            W1(I,J)=W1(I,J)*TEMP
C   60         PHI(I,J)=PHI(I,J)+W1(I,J)/KFACT
C      REM=(L1NORM**(K+1.0D0))/
C     1      (KFACT*(K+1.0D0)*(1.0D0-L1NORM/(K+2.0D0)))
C      IF (K.GT.KCOUNT) GOTO 9000
C      IF (DABS(REM).GT.DELTA) GOTO 1000
CC
C     CONVERGENCE HAS OCCURRED
C
C     DEFINE PHI MATRIX NOW
C
```

```
      DO 60 J=1,N
        PHI(J,J)=1.0D0
 60   CONTINUE
      DO 70 J=1,N,2
        PHI(J,J+1)=DT
 70   CONTINUE
C
C     COMPUTE Q OVER SUBINTERVAL DT/(2**M)
C
      TEMP=DT/(2.0D0**M)
C
CCCC        CALL QCOMP(TEMP,F,PHI,N,QC,Q,W1,W2,M)
C
C
C     WRITE WARNING INFO INTO FILE 99.
CCC         WRITE(99,199) M,K
CCC  199    FORMAT(/'    *** PHICOM ***  M=',I3,'  # OF TERMS =',F5.0)
C
C
C     IF M = 0 THEN RETURN
C          IF M > 0 POWER UP PHI 2**M TIMES
C
      IF (M.EQ.0) GOTO 9999
C
C
C     POWER UP PHI 2**M TIMES
C
            DO   510 I=1,M
  510      CALL ABMULT(PHI,PHI,N,N,N,PHI,W2)
C
C     POWER UP COMPLETE
 9999       RETURN
C
C     CONVERGENCE FAILURE BLOCK.  STOP PROGRAM.
C
 9000       WRITE(6,9100)
 9100    FORMAT(///,41H****  CONVERGENCE FAILED IN PHICOMP  ****,
     1   //,16H**  F MATRIX  **)
      CALL PRINT(F,N,N)
      STOP
C
      END
      SUBROUTINE PRINT(A,M,N)
C
C     SUBROUTINE TO PRINT AN M BY N MATRIX, A.
C
      REAL*8 A(10,10)
      DO 10 I=1,M
        WRITE(6,100) I,(A(I,J),J=1,N)
 10   CONTINUE
 100  FORMAT(//,I5,3X,10(G10.3,1X),/
     1            (8X,10(G10.3,1X)))
      RETURN
      END
      SUBROUTINE QCOMP(DT,F,PHI,N,QC,Q,W1,W2,M)
C
C
C     SUBROUTINE TO COMPUTE THE DISCRETE FORM OF THE
```

```
C     PROCESS NOISE, Q.
C
       IMPLICIT REAL*8 (A-H,P-Z)
C
      REAL*8 PHI(10,10),F(10,10),QC(10,10),Q(10,10)
      REAL*8 W1(10,10),W2(10,10)
      LOGICAL FLAG
C
      DATA RELERR,ABSERR/1.0D-6,1.0D-20/
C
      DO 50 J=1,N
         DO 50 I=1,N
            W1(I,J)=DT*QC(I,J)
   50       Q(I,J)=0.0
C
C     EXPAND Q OVER INTERVAL DT
C
      DO 1000 ITER=2,25
C
C        ADD EXPANSION TERM W1 TO Q
C        COMPUTE W2=DT*F*W1
C
         DO 100 I=1,N
            DO 100 J=1,N
               Q(I,J)=Q(I,J)+W1(I,J)
               SUM=0.0D0
               DO 90 K=1,N
   90             SUM=SUM+F(I,K)*W1(K,J)
  100          W2(I,J)=SUM*DT
C
C     COMPUTE NEXT EXPANSION TERM, W1
C
      SCALE=1.0D0/ITER
      DO 200 J=1,N
         DO 200 I=1,N
            VALUE=(W2(I,J)+W2(J,I))*SCALE
            W1(I,J)=VALUE
  200       W1(J,I)=VALUE
C
C     ZERO OUT NEGLIGIBLE TERMS IN EXPANSION
C
      FLAG=.FALSE.
      DO 300 J=1,N
         DO 300 I=1,N
            IF(DABS(W1(I,J)).LT.(ABSERR+RELER*DABS(Q(I,J)))) GOTO 250
            FLAG=.TRUE.
            GOTO 300
  250       W1(I,J)=0.0D0
  300    CONTINUE
C
C     CONVERGENCE CRITERION IS W1=0
C
      IF(.NOT.FLAG) GOTO 1100
 1000 CONTINUE
 1100 CONTINUE
C
C   IF M = 0 THEN RETURN   ELSE PROPAGATE Q ACROSS INTERVAL DT.
C
```

```
      IF (M .EQ. 0) GOTO 1400
      MAX = 2**M
      DO 1200 J=1,N
         DO 1200 I=1,N
 1200       W1(I,J)=Q(I,J)
C
      DO 1300 I=1,MAX
         CALL KFHPHT(PHI,Q,N,N,Q,W2)
 1300    CALL ABADD(Q,W1,N,N,Q)
 1400 CONTINUE
C
C      WRITE WARNING INFO TO FILE 99.
CCC      WRITE(99,199) ITER
CCC  199 FORMAT(/'  *** QCOMP ***   ITER=',I5)
      RETURN
      END
      SUBROUTINE VPRINT(V,N)
C
C     SUBROUTINE TO PRINT AN N VECTOR, V.
       IMPLICIT REAL*8 (A-H,P-Z)
C
        REAL*8 V(10)
      WRITE(6,100)  (V(J),J=1,N)
  100   FORMAT(//,(10(1X,G10.3)))
      RETURN
      END
C
      FUNCTION TRACE(A,M)
C
C    FUNCTION TO COMPUTE THE TRACE OF THE M BY M MATRIX A.
C
       IMPLICIT REAL*8 (A-H,P-Z)
      REAL*8 A(M,M)
      SUM = 0.0
      DO 10 I=1,M
   10 SUM = SUM + A(I,I)
      TRACE = SUM
      RETURN
      END
C
      SUBROUTINE KFREAD(TIME,DT,NEWDT,EVTAB,PRMTAB,EVENT,
     1            MOD1,MOD2,MOD3,PARMS)
C
C
C     SUBROUTINE TO READ AND INTERPRET THE EVENT TABLE.
C
C
      INTEGER EVENT,MOD1,MOD2,MOD3,PRMTAB(50,80),PARMS(80)
      REAL NEWDT,EVTAB(50,8)
      REAL REVENT,RMOD1,RMOD2,RMOD3
C
      EQUIVALENCE (IEVENT,REVENT),(IMOD1,RMOD1),(IMOD2,RMOD2),
     1             (IMOD3,RMOD3)
C
      DTO2 = DT/2.0
C
      DO 100 INDEX=1,25
         IF (ABS(TIME-EVTAB(INDEX,5)) .GT. DTO2) GOTO 100
```

```
          IF (((TIME .LT. (EVTAB(INDEX,6)+DTO2)) .OR.
     1        (EVTAB(INDEX,6) .EQ. 0.0)) .AND. (EVTAB(INDEX,1) .NE. 0.0))
     2        GOTO 200
          EVTAB(INDEX,5)=1.0E30
  100     CONTINUE
C
C  NO MATCHING TIME, TERMINATE RUN
C
      EVENT = 'STOP'
      GOTO 9999
C
C  TIME MATCH,  SET EVENT AND MODS
C
  200 REVENT = EVTAB(INDEX,1)
      RMOD1  = EVTAB(INDEX,2)
      RMOD2  = EVTAB(INDEX,3)
      RMOD3  = EVTAB(INDEX,4)
C
C  COPY EVENT AND MODIFIERS INTO PARAMETERS FOR RETURN
      EVENT = IEVENT
      MOD1 = IMOD1
      MOD2 = IMOD2
      MOD3 = IMOD3
C
C  SET PARMS,  0 IN EVTAB(INDEX,8) IMPLIES NO PARMS
C
      IPARM = EVTAB(INDEX,8)
      IF (IPARM .EQ. 0) GOTO 350
      DO 300 I=1,80
          PARMS(I)=PRMTAB(IPARM,I)
  300     CONTINUE
      GOTO 450
  350 DO 400 I=1,80
      PARMS(I)=' '
  400 CONTINUE
  450 CONTINUE
C
C  UPDATE EVENT NEXT TIME
C
      EVTAB(INDEX,5) = EVTAB(INDEX,5) + EVTAB(INDEX,7)
      IF (EVTAB(INDEX,7).EQ.0.0) EVTAB(INDEX,5)=EVTAB(INDEX,5)+DT
      IF (EVTAB(INDEX,6) .EQ. 0) EVTAB(INDEX,5)=1.0E30
C
C  IF EVENT IS PROP THEN CHECK FOR NEW DT
C
      IF (EVENT .EQ. 'PROP') GOTO 500
C
C  IF EVENT IS AT LAST TIME SET NEXT TIME TO INFINITY
C
      IF (EVTAB(INDEX,5) .GT. (EVTAB(INDEX,6)+DTO2))
     1    EVTAB(INDEX,5)=1.0E30
      GOTO 9999
C
C  PRPROPAGATE EVENT DT CHECK
C
  500 CONTINUE
C  IF NOT AT THE END OF A PROPAGATE SEQUENCE THEN RETURN
C
```

```
      NEWDT = DT
      IF (ABS(EVTAB(INDEX,5)-EVTAB(INDEX,6)) .GT. DTO2) GOTO 9999
C
C
C   FIND NEXT PROPAGATE SEQUENCE IF IT EXISTS AND SET NEW DT
C
      DO 600 J=21,25
         IF (ABS(EVTAB(INDEX,5)-EVTAB(J,5)) .LT. DTO2  .AND.
     1        INDEX .NE. J)  GOTO 700
  600    CONTINUE
C
C   NO NEW PROPAGATE SEQUENCE
      NEWDT = DT
      EVTAB(INDEX,5) = 1.0E30
      GOTO 9999
C
C   NEW PROPAGATE SEQUENCE.  SET NEW DT.
C
  700 NEWDT = EVTAB(J,7)
      EVTAB(INDEX,5) = 1.0E30
C
 9999 CONTINUE
      RETURN
      END
C
C
       SUBROUTINE HGPS1(H,R)
C
C THIS SUBROUTINE COMPUTES THE H MATRIX FOR GPS CLOCK MEAS.
C              GPS - CS486
C
       REAL*8 H(10),R,SIGGPS,SIGCLK(3)
C
       COMMON/MEASIG/SIGGPS,SIGCLK
C COMPUTE THE NON-ZERO ENTRIES OF H
C
       WRITE(6,*) ' NOW IN HGPS1 SUBROUTINE'
       H(1)=-1.0D0
C
C MEAS. NOISE
C
       R=DSQRT(SIGGPS**2+SIGCLK(1)**2)
C
       RETURN
C
C
C
C*****************END SUBROUTINE HGPS1*************************
C
C
       END
C
C
       SUBROUTINE HGPS2(H,R)
C
C THIS SUBROUTINE COMPUTES THE H MATRIX FOR GPS CLOCK MEAS.
C             GPS - CS124
C
```

```
      REAL*8 H(10),R,SIGGPS,SIGCLK(3)
C
      COMMON/MEASIG/SIGGPS,SIGCLK
C COMPUTE THE NON-ZERO ENTRIES OF H
C
      WRITE(6,*) ' NOW IN HGPS2 SUBROUTINE'
      H(3)=-1.0D0
C
C MEAS. NOISE
C
      R=DSQRT(SIGGPS**2+SIGCLK(2)**2)
C
      RETURN
C
C
C
C*****************END SUBROUTINE HGPS2*************************
C
C
      END
C
C
      SUBROUTINE HGPS3(H,R)
C
C THIS SUBROUTINE COMPUTES THE H MATRIX FOR GPS CLOCK MEAS.
C              GPS - CS017
C
      REAL*8 H(10),R,SIGGPS,SIGCLK(3)
C
      COMMON/MEASIG/SIGGPS,SIGCLK
C COMPUTE THE NON-ZERO ENTRIES OF H
C
      WRITE(6,*) ' NOW IN HGPS3 SUBROUTINE'
      H(5)=-1.0D0
C
C MEAS. NOISE
C
      R=DSQRT(SIGGPS**2+SIGCLK(3)**2)
C
      RETURN
C
C
C
C*****************END SUBROUTINE HGPS3*************************
C
C
      END
C
C
      SUBROUTINE HCLK1(H,R)
C
C THIS SUBROUTINE COMPUTES THE H MATRIX FOR ONLINE CESIUM CLOCK MEAS.
C
      REAL*8 H(10),R,SIGGPS,SIGCLK(3)
C
      COMMON/MEASIG/SIGGPS,SIGCLK
C COMPUTE THE NON-ZERO ENTRIES OF H
C
```

```
      WRITE(6,*) ' NOW IN HCLK1 SUBROUTINE'
      H(1) = 1.0D0
      H(3) =-1.0D0
C
C MEAS. NOISE
C
      R=DSQRT(SIGCLK(1)**2+SIGCLK(2)**2)
C
      RETURN
C
C
C
C*****************END SUBROUTINE HCLK1*************************
C
C
      END
C
      SUBROUTINE HCLK2(H,R)
C
C THIS SUBROUTINE COMPUTES THE H MATRIX FOR ONLINE CESIUM CLOCK MEAS.
C
      REAL*8 H(10),R,SIGGPS,SIGCLK(3)
C
      COMMON/MEASIG/SIGGPS,SIGCLK
C COMPUTE THE NON-ZERO ENTRIES OF H
C
      WRITE(6,*) ' NOW IN HCLK2 SUBROUTINE'
      H(1) = 1.0D0
      H(5) =-1.0D0
C
C MEAS. NOISE
C
      R=DSQRT(SIGCLK(1)**2+SIGCLK(3)**2)
C
      RETURN
C
C
C
C*****************END SUBROUTINE HCLK2*************************
C
C
      END
C
      SUBROUTINE KFUSER(MJDAY,TIME,DT,MOD1,MOD2,MOD3,P,F,PHI,Q,QC,
     *  H,K,R,WT,W1,W2,W3,W4,PARMS,M,N,X)
C
C       W3 ARRAY CONTAINS MEASUREMENT RESIDUALS
C       W4 ARRAY CONTAINS RAW MEASUREMENTS
C
      REAL*8 P(10,10),F(10,10),PHI(10,10),Q(10,10),QC(10,10),
     *  H(10),K(10),WT(10,10),W1(10,10),W2(10,10),X(10),SIG(10)
     *  ,STIME,TIME,DT,R,R2D,MJDAY,W3(10),W4(10)
C
      INTEGER PARMS(80),MOD1,MOD2,MOD3
C
      WRITE(6,*) 'NOW IN KFUSER, PRINTING P'
      WRITE(6,*) TIME
      WRITE(6,*) (P(I,I),I=1,10)
```

```
C
      DO 10 I = 1,N
        SIG(I) = DSQRT(P(I,I))
   10 CONTINUE
C
C
      WRITE(6,*) 'CLOCK UNCERTAINTY (1 SIGMA,micro-SEC)'
      WRITE(6,*) (SIG(I),I=1,N)
C
C      STIME = TIME - 0.5D0
      STIME = TIME

      IF(MOD1.EQ.'LTUS') CALL LOTUS(X,SIG,W3,W4,MJDAY,STIME,N)
C
      RETURN
      END
C
C**************** END OF KFUSER ********************
C
C
      SUBROUTINE LOTUS(X,SIG,W3,W4,MJDAY,TIME,N)
C
C
C
      REAL*8 SIG(10),TIME
      REAL*8 X(10),MJDAY,W3(10),W4(10)
      INTEGER N
C
C
C
      WRITE(20,100) MJDAY,TIME,(X(J),J=1,N),(SIG(I),I=1,N),
     +              (W3(K),K=1,5),(W4(K),K=1,5)
C
  100 FORMAT(1X,F7.1,1X,F5.1,12(1X,F8.5),5(1X,F8.5),5(1X,F8.5))
C
      RETURN
      END
C
C
      SUBROUTINE KFTABL(EXTAB,IPTAB)
      DIMENSION ETAB(50,8),ITAB(50,8),IPTAB(50,80)
      CHARACTER*1 IREC(80)
      CHARACTER*4 IEVENT
      CHARACTER*4 IPARMC
      CHARACTER*4 IRESL
      DIMENSION EXTAB(50,8)
      LOGICAL EOF
      DIMENSION IEVENT(8)
      EQUIVALENCE(ETAB,ITAB)
      IEVENT(1) = 'PROP'
      IEVENT(2) = 'UPDT'
      IEVENT(3) = 'PRNT'
      IEVENT(4) = 'STOR'
      IEVENT(5) = 'RDUP'
      IEVENT(6) = 'USER'
      IEVENT(7) = 'STOP'
      IEVENT(8) = 'TRAJ'
C
```

```
      IPARMC = 'PARM'
      EOF = .FALSE.
C
C
      ICNTE = 0
      NREC = 0
      ICNTP = 0
      IBAD = 0
      IPRCNT = 0
      IVNT = 0
      NTRY = 0
      MTRY = 0
C
C  WRITE OUT A HEADER
C
C
C OPEN THE FILE FOR GETREC
C
      LUN=21
      OPEN(LUN,FILE='KFTABL.IN',ACCESS='SEQUENTIAL',
     1     FORM='FORMATTED')
C
      WRITE(6,90500)
C
C READ A RECORD
C
 10   CALL GETREC(LUN,IREC,NREC,EOF)
C
C CHECK FOR EOF
C
      IF(EOF) GO TO 9999
C
C CHECK FIRST 4 CHARACTERS
C
      IFIRST = 1
      ISIZE = 4
      CALL BLDWRD(IREC,IFIRST,ISIZE,IRESL)
C
C IS IT A PARM CARD?
C
      IF(IRESL .EQ. IPARMC) GO TO 6000
C
C NOT A PARM SO IS IT A VALID EVENT?
C
      ITYPE = 0
      DO 100 I = 1,8
        IF(IRESL .EQ. IEVENT(I)) ITYPE = I
 100  CONTINUE
C     WRITE(6,101)ITYPE
 101  FORMAT(1X,'ITYPE-',I5)
      IF(ITYPE .EQ. 0) GO TO 7000
C
C A GOOD EVENT SO PROCESS IT
C FOR NO VALIDATION OF MODS EXCEPT FOR SI/ZE AND NUMBER
C
C WE WILL USE THIS COMPUTED GOTO LATER
C
C     GO TO(5100,5200,5300,5400,5300,5300,5300,5300),ITYPE
```

```
      GO TO 5300
C
 5300 CONTINUE
C
C NO LIMIT ON THE PARMS FIELDS HERE
C
      IF(ITYPE .EQ. 1) GO TO 5310
      NTRY = NTRY + 1
      MTRY = NTRY
      ITAB(MTRY,1) = IRESL
C
      GO TO 5320
 5310 IPRCNT = IPRCNT + 1
      MTRY = IPRCNT + 20
      ITAB(MTRY,1) = IRESL
 5320 IF(NTRY .GT. 20 .OR. IPRCNT .GT. 5) GO TO 7100
C
      CALL SGEN(IREC,MTRY,ISTAT,ETAB)
      IF(ISTAT.EQ.1) GO TO 5330
      IVNT = 1
      GO TO 10
 5330 IBAD = IBAD + 1
      IVNT = 0
      GO TO 10
C
C HERE TO PROCESS PARMS
C
 6000 CONTINUE
      IF(IVNT .EQ. 0) GO TO 7200
      ICNTP = ICNTP + 1
      IVNT = 0
      DO 6100 I=1,80
        IPTAB(ICNTP,I) = IREC(I)
 6100 CONTINUE
C
C UPDATE THE POINTER TO THE PARM IN THE EVENT RECORD
C
      ETAB(MTRY,8) = ICNTP
C
      WRITE(6,888)ICNTP
  888 FORMAT(1X,'MAIN  IPTAB',I5)
C
C
      GO TO 10
C
C OUTPUT ERROR MESSAGES
C
 7000 WRITE(6,90000) IREC
      IBAD = IBAD + 1
      IVNT = 0
      GO TO 10
 7100 WRITE(6,90010)
      IBAD = IBAD + 1
      IVNT = 0
      GO TO 10
 7200 WRITE(6,90020) IREC
      IBAD = IBAD + 1
      IVNT = 0
```

```
      GO TO 10
C
 9999 CONTINUE
      IF(IBAD .EQ. 0) GO TO 10000
      WRITE(6,90030)IBAD
      STOP 77
10000 CONTINUE
      WRITE(6,90040)
C     RETURN
      DO 3333 I=1,25
      WRITE(6,90100)ITAB(I,1),ITAB(I,2),ITAB(I,3),ITAB(I,4),
     1               ETAB(I,5),ETAB(I,6),ETAB(I,7),ETAB(I,8)
 3333 CONTINUE
      IF (ICNTP.GT.0) THEN
        DO 3334 I=1,ICNTP
          WRITE(6,90200)(IPTAB(I,J),J=1,80)
 3334   CONTINUE
      END IF
C
C SWAP THE OUTPUT TABLE BACK
C
      DO 10020 I=1,25
        DO 10010 J=1,8
          EXTAB(I,J) = ETAB(I,J)
10010   CONTINUE
10020 CONTINUE
C
      RETURN
C
C FORMAT STATEMENTS
C
90100 FORMAT(4(1X,A4),3(1X,F10.2),1X,F6.2)
90200 FORMAT(1X,80A1)
90000 FORMAT(1X,'BAD CARD TYPE'/1X,80A1//)
90010 FORMAT(1X,'TOO MANY PARM OR EVENT CARDS'//)
90020 FORMAT(1X,'PARM WITHOUT EVENT'/1X,80A1)
90030 FORMAT(1X,'UNSUCCESSFUL TABLE BUILD'/
     1       1X,'NUMBER OF ERRORS DETECTED = ',I10)
90040 FORMAT(1X,'SUCCESSFUL TABLE BUILD',//)
90500 FORMAT(//,5X,'EVENT FILE',/)
      END

      SUBROUTINE GETREC(LUN,INDAT,NREC,EOF)
C
CTHIS ROUTINE READS IN A RECORD FROM (LUN) AND RETURNS
C THE RESULT AS AN 80 CHARACTER ARRAY, INDAT
C IF THE READ IS SUCESSFUL,IRSTAT = 1.
C IF EOF OCCURS, IRSTAT=0
C IF ANY ERROR OCCURS IRSTAT=-1
C (NREC)=NUMBER OF RECORDS READ
C
      CHARACTER*1 INDAT(80)
      LOGICAL EOF
C
C     WRITE(6,888)
  888 FORMAT(1X,'ENTER GETREC')
C
C
```

```
C
      READ(LUN,90000,END=10)INDAT
      NREC=NREC + 1
90010 FORMAT(1X,80A1)
C
C EOF ENCOUNTERED
C
      GO TO 20
   10 EOF = .TRUE.
C
      NREC = NREC - 1
C
   20 IF(.NOT. EOF) WRITE(6,90010)INDAT
      RETURN
C
90000 FORMAT(80A1)
C
      END
C
      SUBROUTINE FINDC(ICH,IDATA,ISTART,ILOC)
C
C THIS SUBROUTINE SEARCHES FOR THE CHARACTER (ICH) IN THE
C 80 CHARARCTER STRING (IDATA) BEGINNING AT POSITION (ISTART)
C AND RETURNS THE LOCATION OF (ICH) IN (ILOC) OR RETURNS
C (ILOC=0) IF (ICH) IS NOT FOUND
C
      CHARACTER*1 ICH,IDATA(80)
C
C MINOR ERROR CHECKING
C
      IF(ISTART .LT. 1 .OR. ISTART .GT. 80) STOP 30
C
      ILOC = 0
C
      DO 100 I = ISTART,80,1
          IF(ICH .NE. IDATA(I)) GO TO 100
C
C FOUND IT
C
          ILOC = I
          GO TO 110
  100 CONTINUE
C
  110 CONTINUE
C     WRITE(6,888)ICH,ISTART,ILOC
  888 FORMAT(1X,'FINDC',1X,A1,2(1X,I3))
C
      RETURN
C
C
C
      END
C
      SUBROUTINE BLDWRD(IDATA,ISTART,ILEN,IOUT)
C
C THIS SUBROUTINE TAKES INDIVIDUAL ARRAY ELEMENTS FROM
C (IDATA) BEGINNING AT (IDATA(ISTART)) FOR LENGTH (ILEN)
C CHARACTERS, AND ENCODES THEM INTO A SINGLE WORD IN (IOUT)
```

```
C A MAXIMUM OF 4 CHARACTERS MAY BE ENCODED. THIS IS FOR
C ALPHA STRINGS ONLY.
C
      CHARACTER*1 IDATA(80)
      CHARACTER*4 IOUT
      IOUT='    '
C
C     WRITE(6,888)ISTART,ILEN
  888 FORMAT(1X,'ENTER BLDWRD  IST  IEND',1X,2I10)
C
C
      IEND = ISTART + ILEN - 1
      GO TO (100,200,300,400),ILEN
C
  100 WRITE(IOUT,90000) IDATA(IEND)
      GO TO 10000
  200 WRITE(IOUT,90010)(IDATA(I),I=ISTART,IEND)
      GO TO 10000
  300 WRITE(IOUT,90020)(IDATA(I),I=ISTART,IEND)
      GO TO 10000
  400 WRITE(IOUT,90030)(IDATA(I),I=ISTART,IEND)
C
C
  889 FORMAT(1X,'BLDWRD WORDOUT',1X,'(',A4,')')
C
C
C10000 WRITE(6,889)IOUT
10000 CONTINUE
      RETURN
C
90000 FORMAT(A1)
90010 FORMAT(2A1)
90020 FORMAT(3A1)
90030 FORMAT(4A1)
      END
C
      SUBROUTINE BLDNUM(IDATA,ISTART,IDEC,IEND,RESL)
C
C ISTART = FIRST DIGIT OF FIELD
C IEND = LAST DIGIT OF THE FIELD
C IDEC = LOCATION OF DECMAL POINT
C IDATA = INPUT STRING
C RESL = THE RESULTING NUMBER
C
C     CHARACTER*10 ET
      CHARACTER*1 IDATA(80)
C
C BUILD INTEGER PORTION OF THE NUMBER
C
C     WRITE(6,888)ISTART,IDEC,IEND
  888 FORMAT(1X,'ENTER BLDNUM',3(1X,I5))
C
C
      J = 0
      RESL = 0.0
      ILAST = IDEC - 1
      ICNT = ILAST - ISTART
C
```

```
      DO 100 I = ISTART,ILAST,1
          READ(IDATA(I),90000) IDIGIT
          IPOW = 10 ** (ICNT - J)
          RESL = RESL + IDIGIT * IPOW
          J = J + 1
  100 CONTINUE
C
C NOW DO THE FRACTIONAL PORTION
C
C IF IEND = IDEC YOU ARE DONE
C
      IF(IEND .EQ. IDEC) GO TO 1000
C
      JSTART = IDEC + 1
      K = 1
C
      DO 200 I = JSTART,IEND,1
          READ(IDATA(I),90000) IDIGIT
C     WRITE(6,886)I,IDIGIT,IDATA(I)
  886 FORMAT(1X,'I,IDIG,IDAT ',3I10)
          XPOW = 10.0 ** (-K)
          RESL = RESL + IDIGIT * XPOW
      K = K + 1
C
C     WRITE(6,887)I,IDIGIT,XPOW,RESL
  887 FORMAT(1X,'I-ID-IP-RESL',2(1X,I10),2(1X,F14.8))
C
  200 CONTINUE
C
 1000 CONTINUE
C
C     WRITE(6,889)ISTART,IDEC,IEND,RESL
  889 FORMAT(1X,'BLDNUM S D E R',3(1X,I5),F20.4)
C
      RETURN
C
90000 FORMAT(I1)
C
      END

      SUBROUTINE SGEN(IREC,NTRY,ISTAT,ETABLE)
      DIMENSION LMOD(3)
      DIMENSION ETABLE(50,8)
      CHARACTER*1 IREC(80)
      CHARACTER*1 ILPAR,IRPAR,ICOMM,JA,JB,JF,JT,IBLK,IPT
      CHARACTER*4 AETAB,ISP
      ILPAR = '('
      IRPAR = ')'
      ICOMM = ','
      JA = 'A'
      JB = 'B'
      JF = 'F'
      IBLK = ' '
      IPT = '.'
      JT = 'T'
      ISP = '    '
C
C IREC- INPUT STRING
```

```
C NTRY - THE TABLE ENTERY
C ISTAT=0 IF OK, =1 IF ERROR
C LMOD = LOCATIONS OF COMMAS IN MODS
C
C FIRST SEARCH FOR MODS
C BEGIN LOOKING FOR ( IN CARD COLUMN 5
C
C     WRITE(6,888)
  888 FORMAT(1X,'ENTER SGEN')
C
      NMODS = 0
      LMOD(1) = 0
      LMOD(1) = 0
      LMOD(2) = 0
      LMOD(3) = 0
      LMOD(2) = 0
      LMOD(3) = 0
      IREST = 5
      CALL FINDC(ILPAR,IREC,IREST,ILOC)
C
C IF ILOG = 0 THEN ASSUME NO MODS
C
      IF(ILOC .EQ. 0) GO TO 1000
C
C FOUND OPEN LOOK FOR CLOSE
C
      IOP = ILOC + 1
      CALL FINDC(IRPAR,IREC,IOP,ILOC)
C
C IF WE DID NOT FIND ) THEN AN ERROR
C
      IF(ILOC .EQ. 0) GO TO 5000
C
C IOP WILL BE THE FIRST CHARACTER OF MODS, IOC THE LAST CHARACTER
C NOT INCLUDING THE PARENS
C
      IOC = ILOC - 1
C
C NOW SEE HOW MANY COMMAS IN THE ()
C BETTER NOT BE MORE THAN 2
C
      NMODS = 1
      DO 10 I = IOP,IOC,1
        IF(IREC(I) .NE. ICOMM) GO TO 10
        LMOD(NMODS) = I
        NMODS = NMODS + 1
        IF(NMODS .GT. 3) GO TO 5000
   10 CONTINUE
C
C NOW IOP IS THE FIRST CHARACTER IN THE STRING OF MODS
C IOC IS THE LAST CHARACTER
C LMOD(1)(2) CONTAINS EITHER 0 OR THE LOCATION OF THE COMMAS
C NMODS IS THE NUMBER OF MODS
C FOR NOW MODS ARE PROCESSED  D U M B  WILL FIX LATER
C
C DO MOD 1
      IREST = IOC + 1
      IFIRST = IOP
```

```
      ILAST = IOC
      ILEN = LMOD(1) - IFIRST
      IF(NMODS .EQ. 1) ILEN = ILAST - IFIRST + 1
      CALL BLDWRD(IREC,IFIRST,ILEN,AETAB)
      ETABLE(NTRY,2) = AETAB
C
C IS THERE ANOTHER MOD?
C
      IF(NMODS .EQ. 1) GO TO 1000
C
C DO MOD 2
C
      ILEN = LMOD(2) - LMOD(1) -1
      IF(NMODS .EQ. 2) ILEN = IOC - LMOD(1)
      IFIRST = LMOD(1) + 1
      CALL BLDWRD(IREC,IFIRST,ILEN,AETAB)
      ETABLE(NTRY,3) = AETAB
C
      IF(NMODS .EQ. 2) GO TO 1000
C
C DO THE THIRD MOD
C
      ILEN = ILAST - LMOD(2)
      IFIRST = LMOD(2) + 1
      CALL BLDWRD(IREC,IFIRST,ILEN,AETAB)
      ETABLE(NTRY,4) = AETAB
C
C MODS ARE DONE
C
 1000 CONTINUE
C
C MODS ARE DONE, NOW DO THE REST
C (IREST) CONTAINS THE STARTING LOCATION FOR THE REST OF THE CARD
C FIRST SEE IF IT IS AN (AT) OR A (FROM)
C
      CALL FINDC(JA,IREC,IREST,ILOC)
      IF(ILOC .EQ. 0) GO TO 2000
C
C PROCESS THE (AT) TIME
C
      ETABLE(NTRY,6) = 0
      ETABLE(NTRY,7) = 0
C
C ILOC CONTAINS THE POSITION OF THE (A)
C ILOC + 3 SHOULD BE THE FIRST DIGIT
C
      I1 = ILOC + 3
C
C FIND THE END POINT OF THE NUMBER
C
      CALL FINDC(IBLK,IREC,I1,ILOC)
      IF(ILOC .EQ. 0) GO TO 5000
      I2 = ILOC -1
C
C NOW FIND THE LOCATION OF THE (DECIMAL POINT)
C PUT IT IN (IPD)
C
      CALL FINDC(IPT,IREC,I1,IPD)
```

```
      IF(IPD .EQ. 0 .OR. IPD .GT. ILOC) GO TO 5000
C
C IPD = LOCATION OF DECIMAL
C I1 = FIRST DIGIT
C I2 = LAST DIGIT
C BUILD ETAB(NTRY,5)
C
      CALL BLDNUM(IREC,I1,IPD,I2,ETABLE(NTRY,5))
C
C THE (AT) CARD IS DONE, SET THE FLAG GOOD AND RETURN
C
      ISTAT = 0
      GO TO 9000
C
 2000 CONTINUE
C
C THIS IS A (FROM) (TO) (BY) CARD
C
C FIND WORD (FROM)
C
      CALL FINDC(JF,IREC,IREST,ILOC)
      IF (ILOC .EQ. 0) GO TO 5000
C ASSUME BLANKS ON BOTH SIDES OF NUMBERS
C
      I1 = ILOC + 5
C
C HOW MANY DIGITS?
C
      CALL FINDC(IBLK,IREC,I1,ILOC)
      IF(ILOC .EQ. 0) GO TO 5000
      I2 = ILOC - 1
C
C FIND THE DECIMAL POINT
C
      CALL FINDC(IPT,IREC,I1,ILOC)
      IF(ILOC .EQ. 0 .OR. ILOC .GT. I2) GO TO 5000
C
      IPD = ILOC
      CALL BLDNUM(IREC,I1,IPD,I2,ETABLE(NTRY,5))
C
C NOW DO THE (TO) WORD
C
      ISTART = I2
      CALL FINDC(JT,IREC,ISTART,ILOC)
      IF(ILOC .EQ. 0) GO TO 5000
C
C SHOULD BE A BLANK BETWEEN (TO) AND NUMBER
C
      I1 = ILOC + 3
C
C FIND I2, THE LAST DIGIT
C
      CALL FINDC(IBLK,IREC,I1,ILOC)
      IF(ILOC .EQ. 0) GO TO 5000
      I2 = ILOC - 1
C
C FIND THE PERIOD
C
```

```
      CALL FINDC(IPT,IREC,I1,ILOC)
      IF(ILOC .EQ. 0 .OR. ILOC .GT. I2) GO TO 5000
      IPD = ILOC
C
      CALL BLDNUM(IREC,I1,IPD,I2,ETABLE(NTRY,6))
C
C DO THE (BY)------------FIND B
C
      ISTART = I2
      CALL FINDC(JB,IREC,ISTART,ILOC)
      IF(ILOC .EQ. 0) GO TO 5000
C
C IF YOU GET HERE YOU GOT (B) SO GET A NUMBER
C
      I1 = ILOC + 3
C
C FIND THE LAST DIGIT
C
      CALL FINDC(IBLK,IREC,I1,ILOC)
      IF(ILOC .EQ. 0) ILOC = 80
      I2 = ILOC - 1
C
C FIND THE DECIMAL POINT
C
      CALL FINDC(IPT,IREC,I1,ILOC)
      IF(ILOC .EQ. 0 .OR. ILOC .GT. I2) GO TO 5000
      IPD = ILOC
C
C DO IT
C
      CALL BLDNUM(IREC,I1,IPD,I2,ETABLE(NTRY,7))
C
C A DEEP SIGHHHHHHHHH, WE ARE DONE!!!!!!!
C
      ISTAT = 0
      GO TO 9000
C
C WE HAVE A PROBLEM SO COME HERE
C
 5000 CONTINUE
      WRITE(6,90000) IREC
      ISTAT = 1
      GO TO 9000
C
 9000 RETURN
C
C FORMAT STATEMENTS
C
90000 FORMAT(1X,'ERROR IN FOLLOWING CARD'/80A1//)
      END
```

J-191-6

USER'S GUIDE FOR GPS/OMEGA COVARIANCE SIMULATION PROGRAM

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Prepared for:
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1. INTRODUCTION

This User's Guide provides instructions for using a software package hereafter referred to as the Covariance Simulation Program (CSP). This guide is intended to familiarize the user with the CSP operation. The hardware suite needed to operate the program is listed and detailed instructions for its use are provided.

The CSP was developed by SYNETICS for the U.S. Coast Guard Omega Navigation System Center under contract DTCG-23-86-A-20022. The models used in this simulation are described in a report entitled "Analysis of GPS Timing Data in Support of Omega System Synchronization: A Cesium Stability Study", also developed under the same contract. The report provides details of the simulation, a source code listing (addendum), and includes a discussion of simulations based on timing data from Omega Stations Norway and Hawaii.

2. USING THE PROGRAM

This section of the report describes the hardware requirements, installation process, and operational procedures required to use the CSP. These instructions will allow a user who is familiar with the format and contents of the input data to successfully operate the program.

2.1 HARDWARE CONFIGURATION ASSUMPTIONS

The CSP is distributed on one 5.25 inch high density diskette. This diskette contains an automatic installation procedure which will load all necessary files to the user's hard disk drive.

The user computer is assumed to be configured as follows:

- IBM PC-AT or AT-compatible clone
- Hard Disk Drive, configured as Logical Device C: with at least 1 megabyte of free RAM memory
- 80287 Math Co-Processor
- 1.2 megabyte 5.25-inch floppy disk drive
- Version 3.1 (or higher) DOS or PC-compatible operating system, such as Microsoft DOS or XENIX, resident on the hard disk
- LOTUS 1-2-3 Release 2.01 installed in a subdirectory named C:\LOTUS on drive C:
- A color or monochrome graphics adapter and display.

The CSP package will automatically install and can be operated on a system which meets these minimum criteria.

2.2 INSTALLATION

The following steps will allow you to automatically install all necessary program and data files for operation of the CSP.

1. *Turn on your computer.*
2. *Once you are at your DOS prompt* (ex. <u>C:\</u>) *insert the program diskette in drive A.*
3. *Type the string* <u>A:</u> *followed by* **<u>ENTER</u>**. *You should now see the DOS prompt* <u>A:\</u> *on your screen.*
4. *Enter the command* **<u>INSTALL</u>** *followed by* **<u>ENTER</u>**.

The installation procedure will create a subdirectory named C:\FILTER and all necessary program and data files will be copied to that directory. While transferring the files from the program diskette to the subdirectory, the installation procedure lists the file names on the screen for the user's information. At the end of the installation process, the following message will appear to indicate successful installation and provide the necessary user instructions to begin the execution of the system:

```
INSTALLATION COMPLETE
TYPE C:
THEN CD \FILTER
THEN FILTER
To begin execution of the system
```

Appendix A lists the directories (and their contents) resulting from the installation procedure. Once the installation is complete, you are ready to begin using the system.

2.3 SYSTEM SETUP

You can initiate the execution of the CSP at any time by entering the following commands from the DOS prompt.

1. *Type* <u>C:</u> *followed by an* **<u>ENTER</u>**.

2. *At the C:\ prompt type* CD \FILTER *followed by an* ENTER.

3. *Type* **FILTER** *followed by an* ENTER.

A Filter Menu (Figure 2.3-1) will appear on the screen.*

```
                         FILTER MENU

               --> 1 - TRANSLATE FILE
                   2 - EDIT EVENTS FILE
                   3 - EDIT PARAMETER FILE
                   4 - RUN A FILTER
                   5 - LOTUS
                   6 - QUIT

January 31, 1990 10:33:57 am    CAPS               Memory: 488 K
                        Press H for Help
```

Figure 2.3-1 Filter Menu Selection Screen

The menu selection is made in one of several ways:

1. *Move the arrow pointer to point to your selection, and press* ENTER.

   You move the arrow pointer by:

   - pressing the space bar to move it downward through the menu selection

---

* Filter Menu was generated using the Automenu Software Management System. This is provided with the CSP package.

- *pressing the up or down arrow to move the pointer up or down through the menu selections*

2. *Highlight your menu selection by the same method as shown above.*

3. *Make your selection directly by:*

   Pressing the number key or function key that corresponds to your selection number

The Filter Menu is accompanied by the on-line help feature that is activated by typing **H** for the "menu help key" display. Typing **H** again returns an extended on-line help narrative. Execution of the CSP follows steps 1-6 in the Filter Menu. Once the execution of the previous selection is complete, the user is brought back to the Filter Menu selection screen. The following sections discuss the operation of each step in detail.

2.4 FILE TRANSLATION

The first step in running the system is the translation process. This is Menu Option 1 (Figure 2.3-1). The translation process prepares USNO Remote Data Acquisition System (RDAS) data (see Section 3.2) for input into the filter. This step has to be executed first, any time a new set of timing data is collected and the user wishes to use this data as an input to CSP. Copy the file of USNO RDAS data into the filter subdirectory using the DOS COPY command. Then use program FILEPROC, activated by the above Filter Menu selection, to scan the input data file and retrieve the required six record fields as indicated in Tables 3.2-1 and 3.2-2, respectively. These data must be configured as shown in Figure 3.2-1. At this point, it should be noted that the program diskette contains timing data files NORWAY1.DAT and HAWAII1.DAT for Omega Stations Norway and Hawaii, respectively.

When Option 1 is selected from the menu, the following messages will be displayed on the screen:

TRANSLATING FILE
PLEASE ENTER INPUT USNO RAW DATA FILENAME:

In response to the filename question, enter the name assigned to the USNO PTTI data file which was copied into the FILTER subdirectory for processing. The input data file to be translated can have any valid DOS file name. For this example we are using the file named NORWAY1.DAT provided with CSP package.

The translation process creates an output file specified by the user at the "PLEASE ENTER OUTPUT DATA FILENAME:" prompt. This file will be used as input for the filter execution which is activated by Menu Option 4. The format of the translation output file is shown in Table 3.2-3 for Norway timing data and in Table 3.2-4 for Hawaii timing data. For this example NORWAY.DAT filename is used.

Within the translation process is a conversion of RDAS timing data. The RDAS data is in units of seconds and in the format described in Section 3.3 of reference 1. For use in the CSP it is necessary to "convert" the data by scaling it to microseconds and changing the format. This conversion is accomplished by a simple algorithm described below:

1. a raw measurement is read from an input data file

2. if a measurement is less than 0.5 seconds, it is multiplied by 10^6; otherwise, 1 is subtracted from it and then it is multiplied by 10^6

3.* the converted measurement is written to an output data file

The translation process will take a few moments to complete. At termination, the following message will be displayed:

STOPPED PROCESSING NORWAY.DAT FILE
Stop - Program terminated

* Although the raw measurements have been processed as described they will be referred to as raw measurements

An example of a complete translation session is shown below:

```
TRANSLATING FILE...
PLEASE ENTER INPUT USNO (RDAS) RAW DATA FILENAME :
NORWAY1.DAT
PLEASE ENTER OUTPUT DATA FILENAME :
NORWAY.DAT
STOPPED PROCESSING NORWAY.DAT FILE
Stop - Program terminated.
```

At the end of the translation process, the user is automatically brought back to the Filter Menu selection screen.

2.5 EVENTS FILE EDITING

The diskette contains a sample events file. You may view this file by printing file KFTABL.IN. An example of an events file is shown in Figure 2.5-1. The event file controls the sequence of execution of the CSP. There are four types of events which are described in detail in Section 3.1 (see also Reference 1). Menu Option 2 provides the user with the capability to modify and update the events file for particular applications.

At this point, the user has to make a decision: to customize the input file for the specific simulation application or skip the editing session and use the default values. Shareware program PC-WRITE is provided and invoked to edit the events file. The name of this file is always KFTABL.IN. When first invoked, PC-WRITE asks if you wish to make a backup copy of KFTABL.IN. If you do, then press function key **F9**. If not, then press **ESC**. At any time during the editing process you can invoke on-screen help by pressing function key **F1** twice.

```
PROP (CNST, STAT) FROM 0.0 TO 31.0 BY 0.5
UPDT (VARY, GPS1, STAT) FROM 0.0 TO 31.0 BY 3.0
UPDT (VARY, GPS2, STAT) FROM 0.0 TO 31.0 BY 3.0
UPDT (VARY, GPS3, STAT) FROM 0.0 TO 31.0 BY 3.0
USER (LTUS) FROM 0.0 TO 31.0 BY 0.5
STOP AT 31.0
```

Figure 2.5-1 Sample Event File

Once the editing process is complete, save the KFTABL.IN events file and exit PC-WRITE by pressing function keys F1 then F2 consecutively. Please note that you do not need to use PC-WRITE to edit the events file. You can use any text editor which creates ASCII files.

When the events file editing session is terminated, the user is automatically returned to the Filter Menu selection window.

2.6 PARAMETER FILE EDITING

Your diskette contains a sample parameter file. You may view this file by printing file PARM.IN. An example of a PARM.IN file is shown in Figure 2.6-1. The values in the parameter list are constants that describe the characteristics of the covariance "scenario" to be simulated. Table 2.6-1 lists the parameter names and units.

The clock record, designated by "CLK=" name, contains the initial phase offset and frequency offset (Ref. 1) estimates for each cesium clock: on-line, secondary and primary in that order. The next four records define the cesium clock error model and the corresponding process noise (Ref. 1). The final record, designated by "SIG=" name, defines the uncertainties for GPS and cesium clock time measurements. Menu Option 3 provides the user with the capability to modify and update the parameter file as desired. At this point, the user has two choices: to customize the input file for the specific simulation application or skip the editing session and use the default values. Shareware program PC-WRITE is provided and invoked to edit the parameter file. The

```
'CLK    = ',0.3570, 0.011461, -0.7380, 0.119371, 1.21, -0.050453
'TIME   = ',0.5, 0.5, 0.5
'COV    = ',0.0001, 0.0016, 0.000225, 0.0016, 0.0000, 0.0016
'ERR    = ',0.03, 15.0, 0.03, 15.0, 0.03, 15.0
'QCOV   = ',0.00036, 0.0, 0.00036, 0.0, 0.00036, 0.0
'SIG    = ',0.050, 0.007, 0.010, 0.008
```

Figure 2.6-1 Sample Parameter File for Norway Data Processing

Table 2.6-1

PARAMETER FILE CONTENTS

RECORD	NAME	VALUE (UNITS)
1	CLK	Initial time offset estimate (μsec), initial frequency estimate (μsec/day).
2	TIME	Paramter used in calculation of Q matrix elements (days)
3	COV	Mean square uncertainty in phase offset estimate (μsec)^2, mean square uncertainty in frequency offset estimate (μsec/day)^2.
4	ERR	Largest jump in cesium frequency offset (μsec/day), corresponding to measurement interval (days)
5	Q COV	Mean square frequency fluctuation (μsec)^2, mean square frequency-rate fluctuation (μsec/day)^2.
6	SIG	Root mean square time measurement error (μsec), GPS or cesium clocks

name of this file is always PARM.IN. When first invoked, PC-WRITE asks if you wish to make a backup copy of PARM.IN. If you do, then press function key **F9**; if not, then press **ESC**. At any time during the editing process you can invoke on-screen help by pressing function key **F1** twice.

Once you have completed the editing process, save the PARM.IN parameter file and exit PC-WRITE by pressing function keys **F1** then **F2** consecutively. Please note that you do not have to use PC-WRITE to edit the parameter file. You can use any text editor which creates ASCII files.

2.7 FILTER EXECUTION

Once you have created your input files, you are now ready to run the filter. The filter will accept as input the following files:

NORWAY.DAT (or HAWAII.DAT) - created by Menu Option 1
(translation process)
KFTABL.IN - created by Menu Option 2
PARM.IN - created by Menu Option 3.

The above files are automatically opened and read by the CSP. As output, the Kalman filter portion of the CSP (GPSSIM) creates a file which will be input to LOTUS 1-2-3. LOTUS is used to create the graphs of data processed during early steps for analysis and display to the user.

To invoke the filter process, select Option 4 from the menu. The following will be displayed:

RUNNING FILTER PROGRAM...
PLEASE ENTER RAW MEASUREMENT DATA FILE

In response to the question, enter the name you have selected for the output file of the translation process. Next, the user has to enter the name of a filter output file: for example, you might select LOTUS.OUT as an output file name. Figure 2.7-1 shows an example of a LOTUS spreadsheet generated by importing this file. Table 2.8-1 defines the data elements in the output file. A file import and other LOTUS functions are described in some detail in the next section. The filter output file is an ASCII file and can be listed for review prior to the next step if desired.

The filter execution process will take a minute or two to complete depending on the entries such as the start and stop times in the event file. At termination, the following messages will be displayed:

```
Stop - Program terminated.
DIRECTORY LISTING OF .OUT FILES

Volume in drive C has no label
Directory of C:\FILTER

LOTUS    OUT    size  mm-dd-yy hh:mm
Strike a key when ready...
```

where mm-dd-yy and hh:mm fields contain the date and time of file generation.

A1: 47596 MENU

Worksheet Range Copy Move File Print Graph Data System Add-In Quit
Global Insert Delete Column Erase Titles Window Status Page Learn

	A	B	C	D	E	F	G	H
1	47596	0	-8.90045	0.01019	-63.9048	0.11755	-24.4203	-0.06232
2	47596	0.5	-8.89536	0.01019	-63.8460	0.11755	-24.4515	-0.06232
3	47596	1	-8.89026	0.01019	-63.7872	0.11755	-24.4827	-0.06232
4	47596	1.5	-8.88517	0.01019	-63.7284	0.11755	-24.5138	-0.06232
5	47596	2	-8.88007	0.01019	-63.6697	0.11755	-24.5450	-0.06232
6	47596	2.5	-8.87498	0.01019	-63.6109	0.11755	-24.5761	-0.06232
7	47599	3	-8.72369	0.05323	28.51411	43.43991	-26.6744	-0.67432
8	47599	3.5	-8.69708	0.05323	50.23407	43.43991	-27.0115	-0.67432
9	47599	4	-8.67047	0.05323	71.95402	43.43991	-27.3487	-0.67432
10	47599	4.5	-8.64385	0.05323	93.67398	43.43991	-27.6859	-0.67432
11	47599	5	-8.61724	0.05323	115.3939	43.43991	-28.0230	-0.67432
12	47599	5.5	-8.59062	0.05323	137.1138	43.43991	-28.3602	-0.67432
13	47602	6	-8.67999	0.03241	35.39664	-4.08099	-27.3883	-0.4402
14	47602	6.5	-8.66379	0.03241	33.35614	-4.08099	-27.6084	-0.4402
15	47602	7	-8.64758	0.03241	31.31565	-4.08099	-27.8285	-0.4402
16	47602	7.5	-8.63138	0.03241	29.27515	-4.08099	-28.0486	-0.4402
17	47602	8	-8.61518	0.03241	27.23466	-4.08099	-28.2687	-0.4402
18	47602	8.5	-8.59897	0.03241	25.19416	-4.08099	-28.4888	-0.4402
19	47605	9	-8.72544	0.00974	32.82698	-0.3704	-27.6606	-0.27409
20	47605	9.5	-8.72057	0.00974	32.64178	-0.3704	-27.7977	-0.27409

01-Feb-90 01:54 PM CAPS

Figure 2.7-1 Sample Worksheet Generated from LOTUS.OUT File

MENU

Worksheet Range Copy Move File Print Graph Data System Add-In Quit
Global Insert Delete Column Erase Titles Window Status Page Learn

	I	J	K	L	M	N	O	P
1	0.00981	0.04	0.01437	0.04	0	0.04	-0.26809	-104.602
2	0.02926	0.04037	0.03109	0.06782	0.02757	0.04037	-0.26809	-104.602
3	0.04923	0.04074	0.05724	0.08718	0.04824	0.04074	-0.26809	-104.602
4	0.06938	0.04111	0.09293	0.10296	0.06868	0.04111	-0.26809	-104.602
5	0.08967	0.04147	0.13619	0.11662	0.08913	0.04147	-0.26809	-104.602
6	0.1101	0.04183	0.18576	0.12884	0.10966	0.04183	-0.26809	-104.602
7	0.0467	0.02213	0.04898	0.08535	0.04669	0.02198	-0.16761	-96.0366
8	0.05749	0.0228	0.07555	0.10141	0.0575	0.02266	-0.16761	-96.0366
9	0.06843	0.02345	0.1158	0.11526	0.06842	0.02331	-0.16761	-96.0366
10	0.07954	0.02408	0.16433	0.12761	0.0795	0.02394	-0.16761	-96.0366
11	0.09085	0.02469	0.21907	0.13887	0.09077	0.02456	-0.16761	-96.0366
12	0.10236	0.02529	0.27906	0.14928	0.10224	0.02517	-0.16761	-96.0366
13	0.0458	0.01783	0.0495	0.09021	0.04579	0.01776	0.13827	126.0512
14	0.05398	0.01865	0.07608	0.10554	0.05395	0.01859	0.13827	126.0512
15	0.06242	0.01944	0.11809	0.1189	0.06237	0.01938	0.13827	126.0512
16	0.07113	0.0202	0.16858	0.13091	0.07105	0.02013	0.13827	126.0512
17	0.08013	0.02093	0.2252	0.14191	0.08002	0.02087	0.13827	126.0512
18	0.0894	0.02163	0.28693	0.15211	0.08926	0.02157	0.13827	126.0512
19	0.04463	0.01735	0.04953	0.09023	0.04462	0.01733	0.17911	-9.86731
20	0.05238	0.0182	0.07609	0.10555	0.05236	0.01818	0.17911	-9.86731

Figure 2.7-1 (con't) Elements I through P of the Sample Worksheet

```
                                                                                MENU
Worksheet  Range  Copy  Move  File  Print  Graph  Data  System  Add-In  Quit
Global  Insert  Delete  Column  Erase  Titles  Window  Status  Page  Learn
          Q          R          S          T          U          V          W          X
1      2.33862       0        0
2      2.33862       0        0
3      2.33862       0        0
4      2.33862       0        0
5      2.33862       0        0
6      2.33862       0        0
7      2.37166       0        0
8      2.37166       0        0
9      2.37166       0        0
10     2.37166       0        0
11     2.37166       0        0
12     2.37166       0        0
13    -1.56137       0        0
14    -1.56137       0        0
15    -1.56137       0        0
16    -1.56137       0        0
17    -1.56137       0        0
18    -1.56137       0        0
19    -1.31694       0        0
20    -1.31694       0        0
```

Figure 2.7-1 (con't) Elements Q through S of the Sample Worksheet

2.8 USING LOTUS

Menu Option 5 will invoke LOTUS 1-2-3. LOTUS is used to provide a data manipulation and graphing capability for the output data file. The following discussions will assume that you have created a file named LOTUS.OUT as the output of the filter process.

Select Menu Option 5 to invoke LOTUS 1-2-3. At the main LOTUS prompt, select 1-2-3. When the main spreadsheet screen appears, follow the steps given below to load the filter output file (LOTUS.OUT) into the spreadsheet for processing. The following commands are provided to facilitate use of LOTUS:

1. / - *Enter Lotus command mode*
2. **F** - *File access sub-menu*
3. **I** - *Import file*
4. **N** - *Import file as numbers*

You will now be prompted for a file name. Assuming a file named LOTUS.OUT, press ESC, then type the file name **C:\FILTER\LOTUS.OUT** followed by the **ENTER** key followed by the **ENTER** key again.

The LOTUS.OUT data file will now be imported into your spreadsheet for processing. This file contains 19 data elements for each time point as shown in Table 2.8-1.

Once the data are loaded into the spreadsheet, the user can select the combination of data elements to be displayed graphically. Only data elements C through S can be graphed. The graphs are presented in standard rectangular xy-coordinates with time on the positive X axis. Any graphics created during these analyses can be printed using the PrintGraph option from the main LOTUS 1-2-3 menu. The user performs the selection in the following manner:

1. *Make sure the main LOTUS 1-2-3 menu is on your screen.*

2. *Move the menu pointer to PrintGraph and press* **ENTER**.

3. *Follow the instructions on the screen if the program asks you to change a disk.*

4. *Enter the command*:

   I - *Select Image-Select. Follow the instructions on the screen to indicate the graphs you want to print.*

   A - *Select Align to tell PrintGraph that the paper is currently positioned at the top of the page.*

   G - *Select GO to begin printing.*

   P - *Select Page to advance the page when printing is complete.*

5. *Type e to select EXIT.*

6. *Type y to confirm that you want to leave PrintGraph.*

Table 2.8-1
LOTUS Output Data File Contents
(NORWAY)

ELEMENT	CONTENT
A	Data Point Modified Julian Date
B	Data Point Time
C	Phase Offset - Online Cesium Clock
D	Frequency Offset - Online Cesium Clock
E	Phase Offset - Primary Cesium
F	Frequency Offset - Primary Cesium
G	Phase Offset - Secondary Cesium
H	Frequency Offset - Secondary Cesium
I	Standard Deviation - Element C above
J	" " - Element D above
K	" " - Element E above
L	" " - Element F above
M	" " - Element G above
N	" " - Element H above
O	GPS - Online Cesium Measurement Residual
P	GPS - Secondary Cesium Measurement Residual
Q	GPS - Primary Cesium Measurement Residual
R	Online - Secondary Cesium Measurement Residual
S	Online - Primary Cesium Measurement Residual

Once you have completed work, the spreadsheet can be saved to disk for future reference by entering the following commands then supplying a file name:

1. / - *Enter LOTUS command mode*
2. **F** - *File access sub-menu*
3. **S** - *Save file*

The user will be automatically returned to the Filter Menu after exiting LOTUS.

3. COVARIANCE SIMULATION

3.1 GENERAL INFORMATION

The CSP is used to predict the phase and frequency offsets, and the prediction uncertainties for the three-cesium frequency standard ensemble at an Omega transmitting station. A Kalman filter is employed to propagate a phase offset and a phase drift rate (frequency offset) covariance matrix, and to update the estimation error covariance, based on assumed cesium standard parameters and initial offset data. Five sets of timing measurements are employed in the estimation process:

- GPS minus on-line cesium clock
- GPS minus primary cesium clock
- GPS minus secondary cesium clock
- On-line cesium clock minus primary cesium clock
- On-line cesium clock minus secondary cesium clock

There are three types of outputs generated for each of cesiums:

- estimates of phase and frequency offsets
- filter determined uncertainties in these estimates
- phase offset residuals (difference between phase offset measurement and phase offset estimate).

Figure 3.1-1 illustrates the computational flow of the simulation. The values in the parameter file are constants that describe the characteristics of the simulated system. Table 2.6-1 lists the parameter names and units. Each line in the table is a record in the PARM.IN file (an example of a PARM.IN file is shown in Figure 2.6-1).

An event file (KFTABL.IN) controls the sequence of execution of the covariance analysis software. There are four types of events used by the CSP:

- The update event (UPDT) updates the covariance to incorporate timing measurements
- The propagate event (PROP) propagates the covariance through a time interval
- The user event (USER) writes data to the filter output file
- The stop event (STOP) terminates the simulation.

Events are scheduled by order of time sequence labeling and by order of appearance in the event list. If several events are scheduled at one time, they will be executed in the order they appear in the event table. The sole exception is the propagation event from time t_k to t_{k+1} which is defined at t_k. It is executed after all other events at t_k and before any other event at t_{k+1}.

The USER event is a general purpose exit from the covariance simulation to perform auxiliary computations on the covariance analysis in progress. In the simulation it is used to generate a LOTUS output file. The LOTUS file is a list of records, each one containing time, phase and frequency estimates, RMS uncertainties in the estimates and measurement residuals.

The STOP event provides the program the ability to terminate normally without processing an entire event file. No records after the first STOP are processed. This permits the user to modify or debug a simulation easily. A full discussion of the simulation model is contained in Reference 1.

The list below describes the operational flow of the simulation in the order that corresponds to the CSP execution.

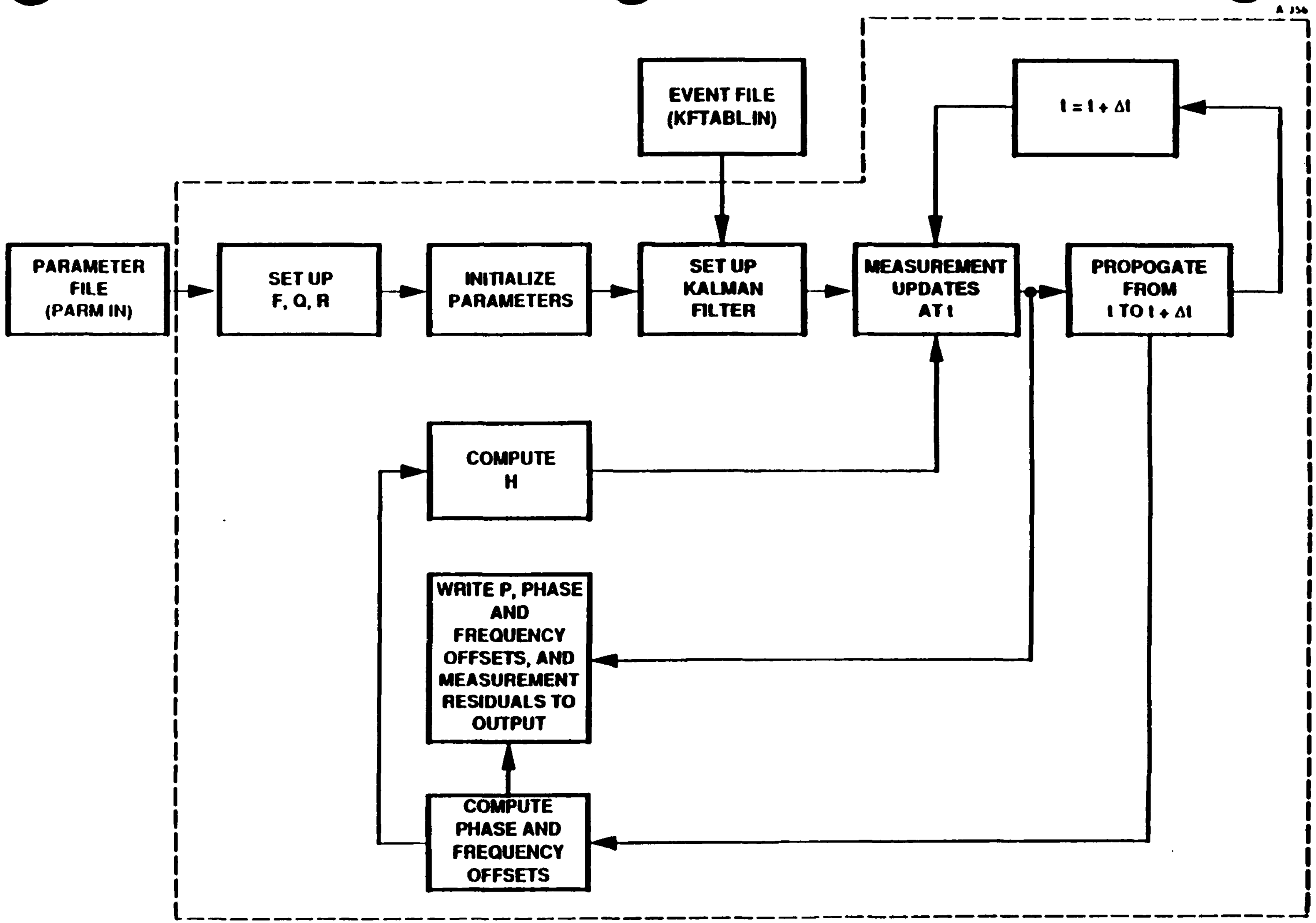

Figure 3.1-1 Simulation Flow Diagram

1. Parameter file (PARM.IN) is read containing initial phase and frequency offsets, parameters defining the cesium clock error model, mean square uncertainties in phase and frequency offset estimates and measurement errors. A description of parameter file contents is provided in Table 2.6-1.

2. The constants contained in the parameter file are used to set the following Kalman filter matrices:

   - F (transition matrix) - transition matrix allows calculation of the state vector (phase and frequency offset) at some time t, given complete knowledge of the state vector at t_0.

   - Q (process noise matrix) - process noise matrix is used to define the system model disturbance (e.g. mean square frequency and frequency-rate fluctuations).

   - R (measurement noise) - measurement noise matrix is used to define the measurement model based on the chosen measurement errors.

3. Initial conditions of the CSP are set: state vector and covariance matrix which defines uncertainty in estimate errors.

4. Event file (KFTABL.IN) is read containing one of the four events as described above.

5. Based on the event type, the next Kalman filter processing step takes place. The normal procedure would be to read a raw measurement, update the covariance matrix and propagate the system estimates.

6. Once the measurement is read, an observation matrix H is defined to relate the measurement to the state vector.

7. The new state vector elements are calculated.

8. The covariance matrix diagonal terms, phase and frequency offsets and measurement residuals are written to an output file.

9. Steps 5 through 8 are repeated until a STOP event is encountered or the final time defined in the event file is reached.

3.2 BRIEF DESCRIPTION OF INPUT DATA

Omega time at each station is derived from one of three Hewlett-Packard CAQI-5061 Cesium Beam Frequency Standards, which are part of the AN/FRN-30 Timing-Control Set. Each frequency standard drives an Omega Signal Format Generator (OMSFOG).

At present, all Omega transmitting stations are equipped with DATUM model 9390-5007 GPS Time/Frequency monitors. USNO RDAS is used to gain access to the input data from Omega Stations Norway and Hawaii. Currently, at these two stations, the RDAS observes, records and reports GPS measurements of UTC minus cesium time before it gets adjusted by OMSFOG, as well as the relative differences in cesium times. This experimental capability to record "uncorrected" data is currently available only at the Omega Stations Norway and Hawaii. A sample of Precise Time/Time Interval (PTTI) data collected by USNO personnel is shown in Figure 3.2-1, an explanation of the records is shown in Table 3.2-1. Each data record field depicted in Figure 3.2-1 is described in Table 3.2-1 for Omega Station Norway. Table 3.2-2 contains record field descriptions for PTTI data provided by Omega Station Hawaii. (Note that the order of measurements for primary and secondary cesium clocks is reversed for Norway station: first, secondary clock data is reported followed by primary clock data).

At USNO a Hewlett-Packard 1000 computer is used to save the PTTI data for collection periods exceeding one week. These data were provided for use in the CSP and are included on the accompanying diskette under filenames NORWAY1.DAT and HAWAII1.DAT.

```
---------------
47552         *
0             *
.999972641    *
.000024502    *
.015946753
.015946998
.999963657    *
.000015517    *
.015937764
.015937972
.999966471
.000018348
.015940531
.015940776
.399977464
.400029324
.415951522
.415951756
99800.3
-.00000249
---------------
47552.0416667  *
100            *
.999972601     *
.000024463     *
.015946627
.015946875
.99996366      *
.000015521     *
.01593768
.015937927
.999966476
.00001834
.015940503
.015940741
.399977467
.40002933
.415951475
.415951685
79700.3
.01594707
---------------
```

Figure 3.2-1 A Sample of PTTI Data Collected by USNO RDAS

* Direct input to the CSP

Table 3.2-1
Covariance Simulation RDAS Timing Measurements
(Omega Station Norway)

Record Field No.	Station Configuration Channel Description	Description of the Data Field
1	NA	Modified Julian Date (MJD) of the data being reported in this record*
2	NA	GMT time of the day*
3	A1-B1	GPS-CS017*
4	A1-B2	GPS-CS124*
5	A1-B3	GPS-LOR1
6	A1-B4	GPS-LOR2
7	A2-B1	CS486-CS017*
8	A2-B2	CS486-CS124*
9	A2-B4	CS486-LOR1
10	A2-B4	CS486-LOR2
11	A3-B1	OMSFOG-CS017
12	A3-B2	OMSFOG-CS124
13	A3-B3	OMSFOG-LOR1
14	A3-B4	OMSFOG-LOR2
15	NA	CLOCK-CS047
16	NA	CLOCK-CS124
17	NA	CLOCK-LOR1
18	NA	CLOCK-LOR2
19	NA	CS486-LORM
20	NA	CS486-LORX

* Direct input to the CSP.

Table 3.2-2
Covariance Simulation RDAS Timing Measurements
(Omega Station Hawaii)

Record Field No.	Station Configuration Channel Description	Description of the Data Field
1	NA	Modified Julian Date (MJD) of the data being reported in this record*
2	NA	GMT time of the day*
3	A1-B1	GPS-CS554*
4	A1-B2	GPS-CS349*
5	A1-B3	GPS-LOR1
6	A1-B4	GPS-LOR2
7	A2-B1	CS529-CS554*
8	A2-B2	CS529-CS349*
9	A2-B4	CS529-LOR1
10	A2-B4	CS529-LOR2
11	A3-B1	OMSFOG-CS554
12	A3-B2	OMSFOG-CS349
13	A3-B3	OMSFOG-LOR1
14	A3-B4	OMSFOG-LOR2
15	NA	CLOCK-CS554
16	NA	CLOCK-CS349
17	NA	CLOCK-LOR1
18	NA	CLOCK-LOR2
19	NA	CS529-LORM
20	NA	CS529-LORX

* Direct input to the CSP.

Of the 20 available data fields from the USNO RDAS, only the following six data fields are utilized by the CSP directly:

1. Modified Julian Date (MJD)

2. GMT Time of the Day (TOD)

3. Time difference between GPS time and secondary cesium clock (GPS-CS017) for Norway Station.

   Time difference between GPS time and primary cesium clock (GPS-CS554) for Hawaii Station

4. Time difference between GPS time and primary cesium clock (GPS-CS124) for Norway Station.

   Time difference between GPS time and secondary cesium clock (GPS-CS349) for Hawaii Station

5. Time difference between on-line and secondary cesium clocks (CS486-CS017) for Norway Station.

   Time difference between on-line and primary cesium clocks (CS529-CS554) for Hawaii Station

6. Time difference between on-line and primary cesium clocks (CS486-CS124) for Norway Station.

   Time difference between on-line and secondary cesium clocks (CS529-CS349) for Hawaii Station.

These are highlighted by an (*) in Table 3.2-1 and listed in the order as they appear in NORWAY.DAT file in Table 3.2-3. Table 3.2-4 provides the analogous summary for HAWAII.DAT.

Table 3.2-3
NORWAY.DAT File Format

RECORD FIELD NO.	RECORD CONTENTS	
1	Modified Julian Day	GMT Time of the Day
2	GPS - CS017 (μsec)	GPS-CS124 (μsec)
3	CS486-CS017 (μsec)	CS486-CS124 (μsec)

Table 3.2-4
HAWAII.DAT File Format

RECORD FIELD NO.	RECORD CONTENTS	
1	Modified Julian Day	GMT Time of the Day
2	GPS - CS554 (μsec)	GPS-CS349 (μsec)
3	CS529-CS554 (μsec)	CS529-CS349 (μsec)

4. COVARIANCE SIMULATION PROGRAM OUTPUT

4.1 SAMPLE RUNS

To demonstrate the CSP performance, a discussion of three different sample runs are presented in this section. Each run was defined by an appropriate update event type that identifies the measurement set and the rate with which the measurement is incorporated into the filter. All three runs were executed on the identical 14-day period USNO RDAS input data for Omega Station Norway with a 3-day scheduled update rate. Table 4.1-1 shows the sensors used for the sample runs.

TABLE 4.1-1
OMEGA STATION NORWAY SENSOR UTILIZATION

SAMPLE RUN NO.	GPS TRANSFER	ON-LINE CESIUM	PRIMARY CESIUM	SECONDARY CESIUM
1	Off	On	On	On
2	On	On	Off	Off
3	On	On	On	On

4.1.1 *Sample Run 1*

Figure 4.1-1 shows the plot of the RMS error value of the phase offset estimate. This plot was generated from a data set consisting of:

- Time difference between on-line and secondary cesium measurements
- Time difference between on-line and primary cesium measurements.

No GPS measurement was applied in this sample run. On the third day the same set of measurements was used to update the uncertainty of the phase estimate based on the relative measurement accuracy, thus bringing the uncertainty value down by about 0.15 μsec. All three cesium clocks followed the same "line of the behavior".

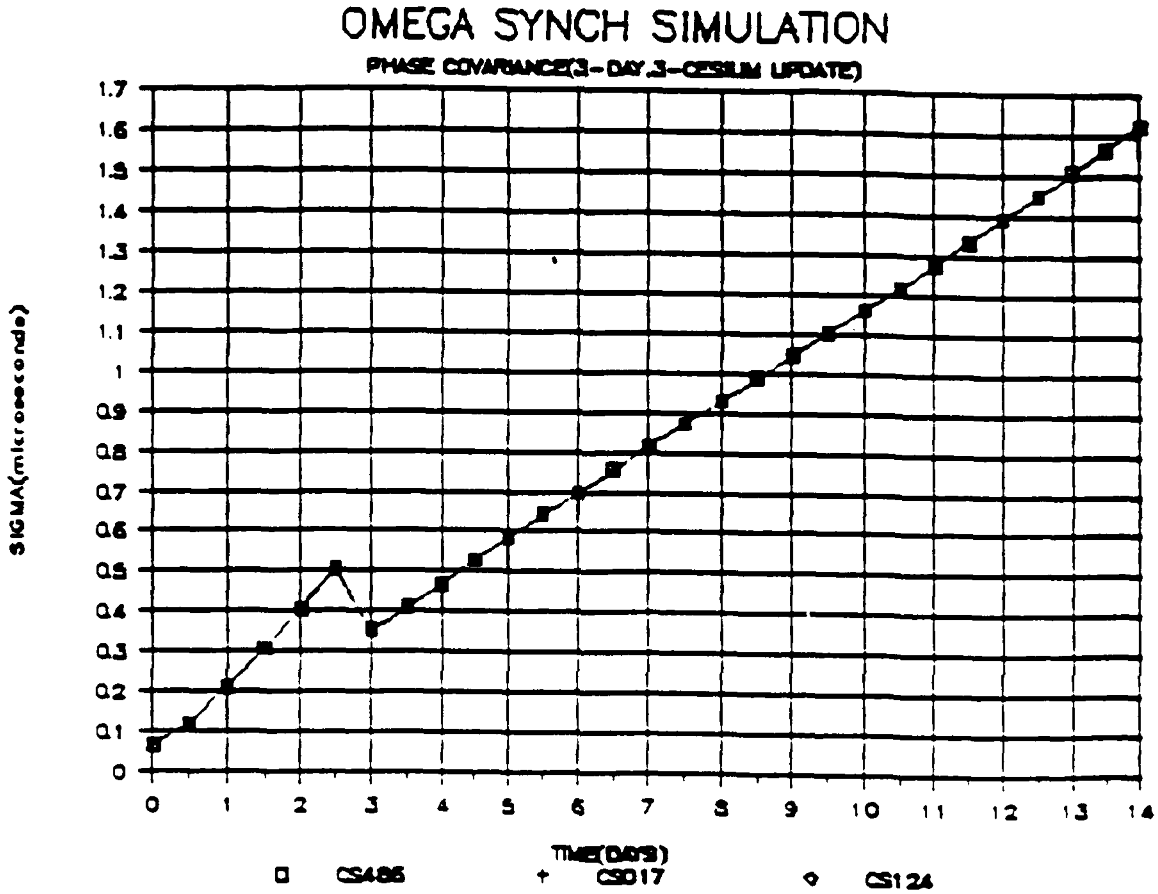

Figure 4.1-1 CS486-CS017, CS486-CS124 Measurement Set (Sample Run 1)

4.1.2 *Sample Run 2*

Figure 4.1-2 shows the plot of the RMS error value of the phase offset estimate for the situation where GPS updates were included for the on-line cesium standard. In this CSP run, it was assumed that only the on-line cesium standard (CS486) was being compared to GPS time at OMSTA Norway. This sample run clearly demonstrates the benefits of the GPS time measurement incorporation into the system dynamics. Even though all three cesiums start out at similar initial conditions, after the first GPS measurement update to the on-line clock, there is a 0.56 μsec difference between the uncertainties of on-line and off-line cesiums. As time progresses, this uncertainty appears to grow without bound for the off-line cesiums. It can also be noted that

incorporating the phase measurements from all three cesiums slows the rate of growth of the phase uncertainty. This can be verified by observing the value of sigmas in Figures 4.1-1 and 4.1-2 at the 14-day mark.

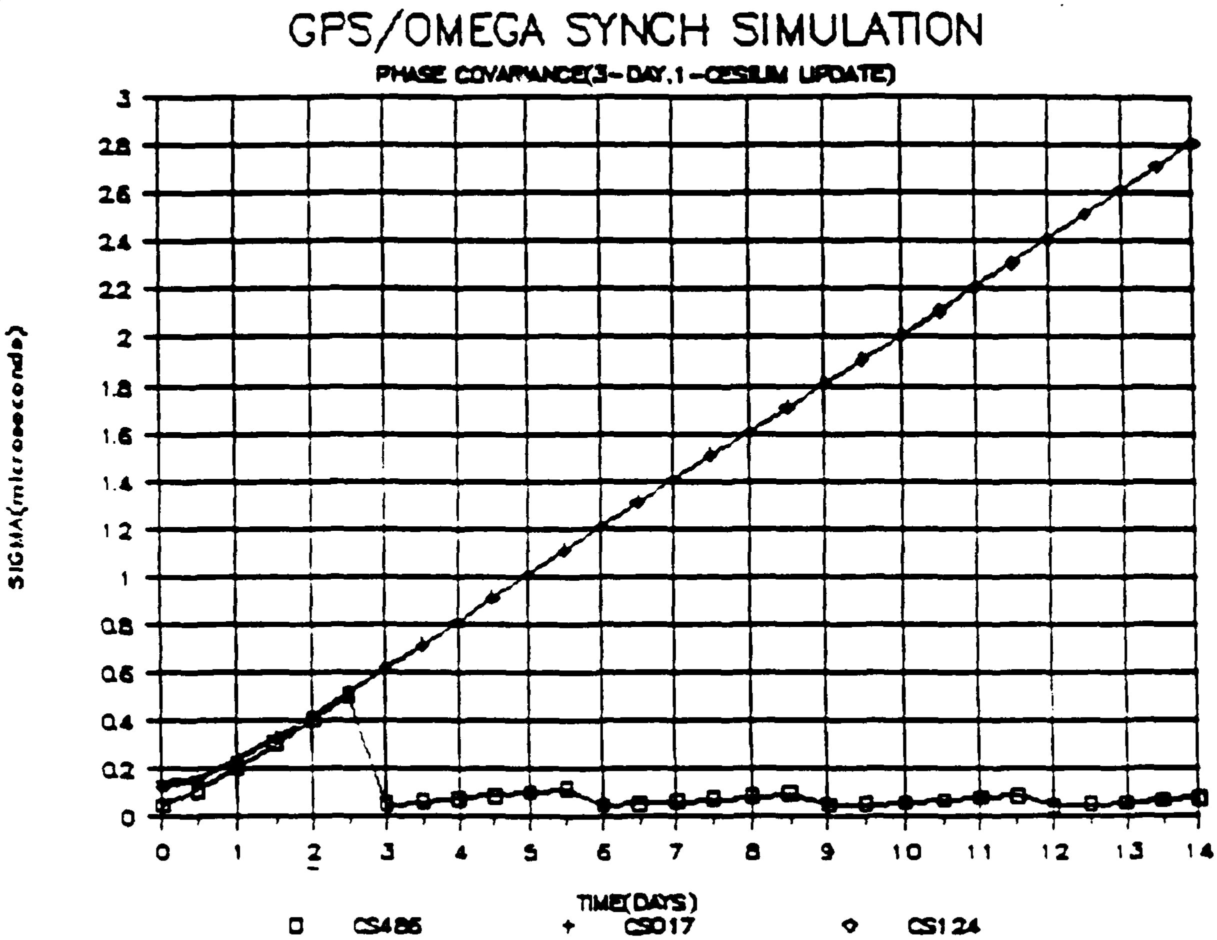

Figure 4.1-2 GPS-CS486 Measurement Set (Sample Run 2)

4.1.3 *Sample Run 3*

In the final sample run, a full station cesium setup was assumed to be active. In other words, all three cesium times were used in conjunction with the GPS time measurement. The resulting cesium clock system performance shown in Figure 4.1-3 resembles the performance of a system consisting of a single on-line cesium clock corrected by the GPS measurements. The combination of the measurements used in this run:

- Time difference between GPS and on-line cesium

- Time difference between on-line and secondary cesiums
- Time difference between on-line and primary cesiums

As is seen in Figure 4.1-3, the phase uncertainty is bounded and well-behaved.

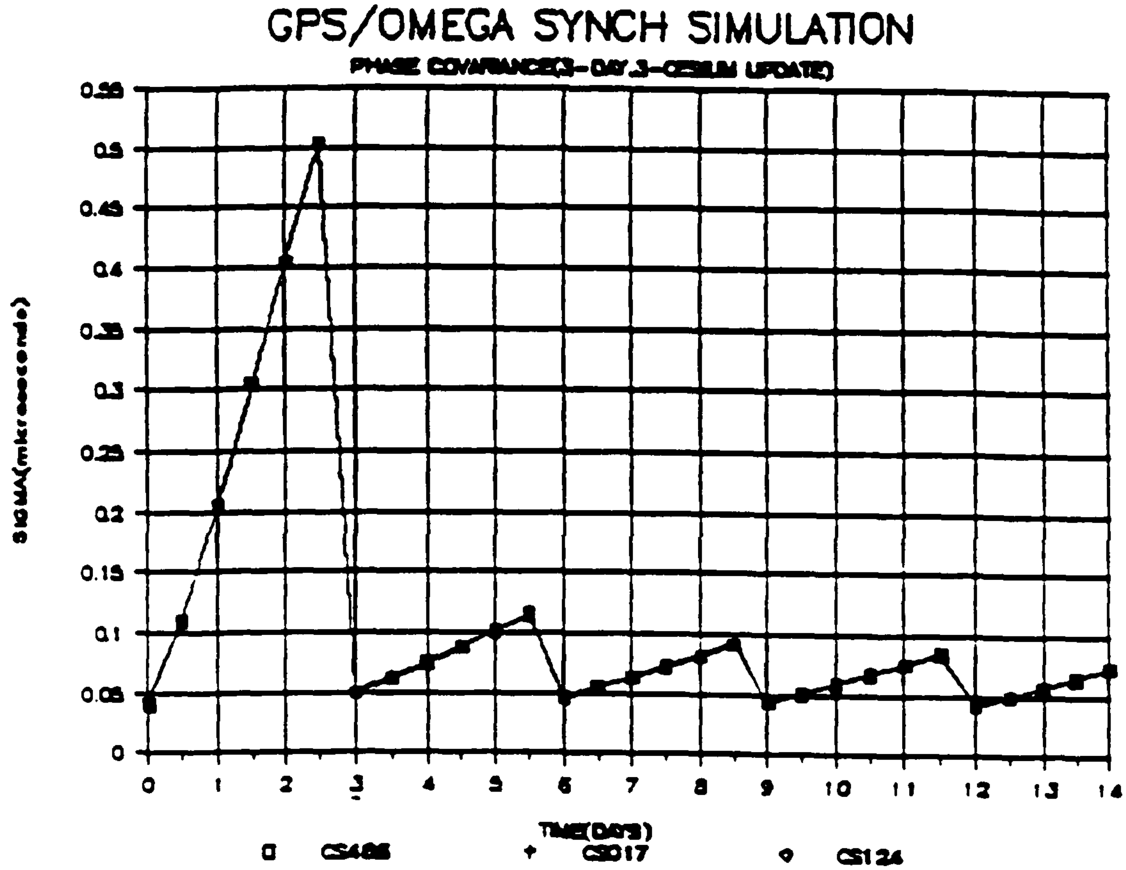

Figure 4.1-3 GPS-CS486, CS486-CS017 and CS486-CS124 Measurement Set (Sample Run 3)

5. REFERENCES

1. "Analysis of GPS Timing Data in Support of Omega System Synchronization: A Cesium Stability Study", ***SYNETICS*** Corporation, DTCG23-86-A-20022, April 1990.

APPENDIX A FILTER.BAT FILES

It is imperative that the following directory and their contents be established in order to ensure proper operation. The INSTALL file on the FILTER distribution diskette will create the FILTER directory and all required files.

C:\FILTER

AUTOMENU.COM	FILTER.BAT
AUTOMENU.MDF	FILTER.MDF
AUTO.BAT	FDBF.BAT
	FOUT.BAT
FILEPROC.EXE	NORWAY1.DAT
GPSSIM.EXE	NORWAY.DAT
PC-WRITE	HAWAII1.DAT
	HAWAII.DAT

C:\LOTUS
LOTUS.COM
And any application-dependent files

FILE NAMES AND FUNCTIONAL DESCRIPTION

AUTOMENU.COM
Executable menu application

AUTOMENU.MDF
Required by AUTOMENU.COM

AUTO.BAT
Executes AUTOMENU.COM

FILTER.BAT
Executes AUTO.BAT with FILTER.MDF

FILTER.MDF
Contains definitions for FILTER menu

FDBF.BAT

Called by FILTER.MDF to display a listing of .DAT and .BAK files of the current directory

NORWAY1.DAT

USNO supplied RDAS timing data for Omega Station Norway

HAWAII1.DAT

USNO supplied RDAS timing data for Omega Station Hawaii

NORWAY.DAT

A file containing converted Norway timing data (output of FILEPROC program)

HAWAII.DAT

A file containing converted Hawaii timing data (output of FILEPROC program)

FILEPROC.EXE

Converts NORWAY1.DAT file into NORWAY.DAT file or HAWAII1.DAT file into HAWAII.DAT file.

GPSSIM.EXE

Runs the Kalman filter simulation software

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply By	To Find	Symbol
	LENGTH			
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (weight)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286. Units of Weights and Measures. Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply By	To Find	Symbol
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
	MASS (weight)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F